International Journal of Environment, Agriculture and Biotechnology
Vol-9, Issue-6; Nov-Dec, 2024
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Analysis of Spatial-Temporal Changes of Land Use in Zhenjiang City, Jiangsu Province, from 2000 to 2020 Using GIS

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Received: 23 Sep 2024; Received in revised form: 20 Oct 2024; Accepted: 27 Oct 2024; Available online: 01 Nov 2024

***Abstract*— *With the rapid growth of the economy and the acceleration of urbanization, the scarcity of land resources has become increasingly prominent, and changes in land use types have become a hot research topic. This study takes Zhenjiang City in Jiangsu Province as an example, using land use data from 2000, 2010, and 2020, and combining ArcGIS with three methods: land use transfer matrix, dynamic degree, and standard deviation ellipse, to analyze the spatiotemporal changes and transfer amounts of land use types in the past two decades. The results indicate that firstly, the land use types in Zhenjiang are cropland, construction land, forests, and water bodies, with the specific area being cropland>construction land>forests>water bodies>wetlands>grasslands. Secondly, forests are distributed in the southwest and northwest of Zhenjiang; wetlands are distributed in the north; water bodies are distributed in the north and central western regions; and construction land is distributed in the north and central regions. Thirdly, in the past two decades, the single land use dynamic degree of construction land has been the highest, at 17.27%, indicating the largest change in area and rapid urban extension in Zhenjiang. The center of gravity of construction land has undergone significant changes, showing a shift from northeast to southwest.*

***Keywords*— Spatiotemporal Changes of Land Use, Transition Matrix (TM), Zhenjiang City, Dynamic Degree, Standard Deviation Ellipse (SDE)**

I. INTRODUCTION

Land is an important component of ecosystems, carrying various biological communities including plants, animals, and microorganisms [1]. The health and stability of land play a crucial role in maintaining ecological balance, protecting biodiversity, and addressing climate change. Research shows that the spatiotemporal changes in land use are one of the main causes of environmental change on Earth [2]. It not only affects the sustainable development of human society but also profoundly impacts the balance of the natural environment and ecosystems. In addition, it also has a profound impact on the structure and function of ecosystems. Therefore, reasonable land use planning is necessary to protect natural ecosystems, maintain ecological balance, and prevent the loss of biodiversity.

In recent years, many scholars at home and abroad have analyzed and studied land use change. For example, Appiah (2015) and other scholars used GIS and RS technologies to analyze the characteristics of land use/cover change (LUCC) in the suburban fringe of Ghana [3]. Enaruvbe (2015) used a combination of supervised and unsupervised classification methods to analyze the patterns and rates of spatiotemporal changes in land cover [4]. In relevant research in China, many scholars choose spatial analysis indicators for land use, such as land use dynamics, standard deviation ellipse models, partial correlation methods, etc., to study the spatiotemporal characteristics of land use changes from the perspectives of land use type transfer, change amount, and change rate. Among them, Wang (2024) and other scholars used partial correlation methods to study the spatiotemporal changes of land use and vegetation cover in arid areas [5]. Research has shown that regions with a significant decrease in Fractional Vegetation Coverage (FVC) ($P<0.1$) are mainly characterized by the transfer of grassland to bare land, while regions with an upward trend are characterized by the transfer of bare land to grassland and grassland to cultivated land. There are more regions with a positive correlation between FVC and precipitation, with a larger proportion of grassland area and a smaller proportion of bare land. Tang (2024) and other scholars used methods such as standard deviation ellipse and land use dynamics to analyze the spatiotemporal changes of land use in the Changjizhou Plain area [6]. The study showed that the transformation between different land types in the study area was most evident in the dynamic changes and center of gravity migration of cultivated land, while the dynamic changes and center of gravity migration of other land types were not significant. Scholars such as Luo (2024) conducted a study on the changes in land use landscape patterns in Qinzhou City from 2000 to 2020 using ArcGIS 10.8 and Fragstats4.2 software [7]. Research has shown that PD, SHDI, and SHEI in the study area continue to decrease, while CONTAG and AI continue to rise. The overall landscape fragmentation in Qinzhou City deepens, land use is abundant, and different landscapes tend to become more complex, with a uniform distribution of types.

Since the reform and opening up, Chinese cities have developed rapidly, with significant improvements in both quantity and scale. Especially in the eastern and southern cities near the coast, their development speed and scale are better than other cities. As an important prefecture-level city in Jiangsu Province, Zhenjiang is a crucial pillar of the province's economic development. Due to the rapid advancement of urbanization, rapid socio-economic development, and the implementation of a series of national planning policies, the demand for construction land continues to increase, and the changes in land use types are increasingly influenced by human activities [8]. Therefore, this study uses ArcGIS software to analyze the land use changes in Zhenjiang City from 2000 to 2020, explore the changes in its spatial pattern, and provide specific targeted measures for land use changes, attempting to provide a scientific basis for regional ecological environment protection and land use planning.

II. RESEARCH AREA

Zhenjiang City is a prefecture-level city under the jurisdiction of Jiangsu Province, China. It is located in the southwest, at the western end of the Yangtze River Delta region, at 31° 37′~32° 19′ N latitude and 118° 58′~119° 58′E longitude [9] (Figure 1). It belongs to the subtropical monsoon climate with distinct four seasons, warm and humid, and has three major water systems: Huxi, Yanjiang, and Qinhuai River. The city has undulating terrain and diverse landforms. Among them, the plain area accounts for 15.5% of the total area, hilly and mountainous areas account for 51.1%, water areas account for 13.7%, and polder areas account for 19.7%. This terrain condition provides abundant natural resources and diverse ecological environments for the development of Zhenjiang City.

The permanent population of Zhenjiang continues to grow. According to statistical data, from the end of 2023 to the beginning of 2024, the permanent population will reach 3.226 million, including 2.6034 million urban populations, with an urbanization rate of as high as 80.7% [10]. In addition, the population structure is constantly changing, and the proportion of the elderly population is increasing year by year. In terms of economy, the municipal government actively promotes the green and low-carbon transformation of industries and cultivates and develops new quality productive forces [11]. In recent years, with the gradual improvement of the green manufacturing system, a group of high-quality green manufacturing units have emerged. At the same time, the installed capacity of renewable energy continues to expand, and various types of energy storage development are actively promoted, injecting new vitality into the economic and social development of Zhenjiang.

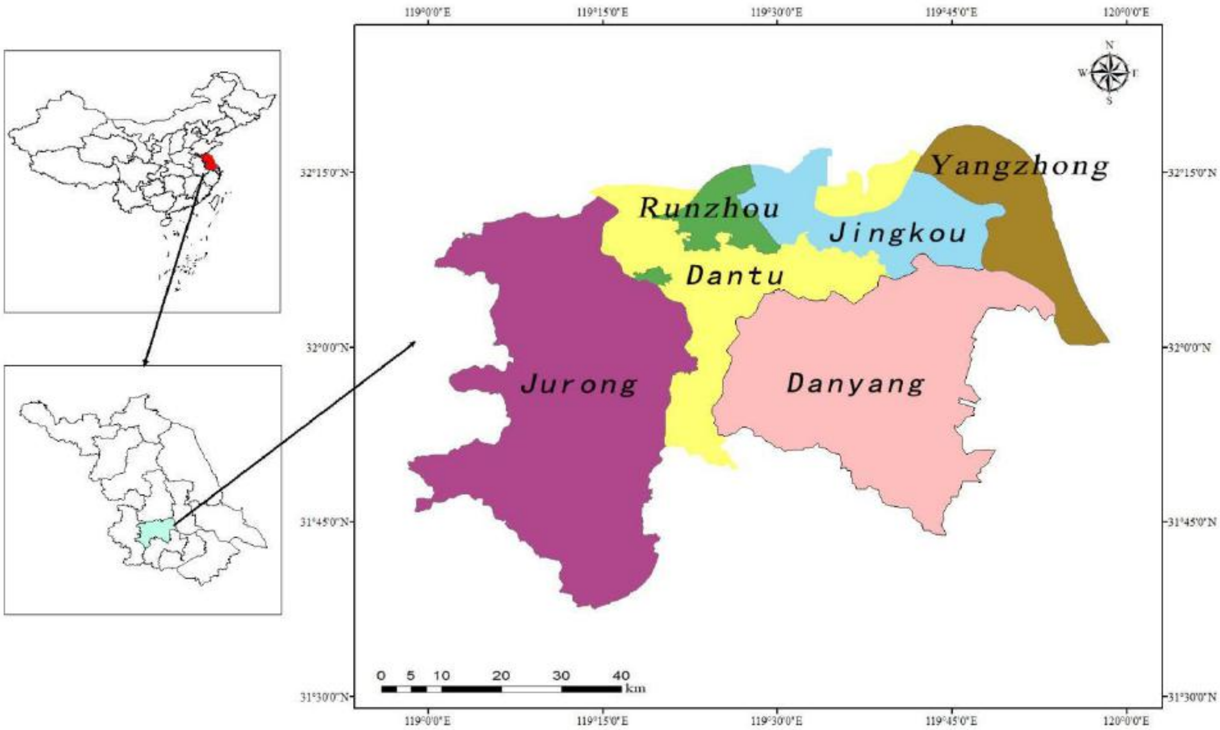

Fig.1 Administrative Region Map of Zhenjiang City

III. DATA SOURCES AND ANALYSIS METHODS

3.1 Data Sources

The research data selected in this article is mainly divided into raster data and vector data. Among them, the raster data includes elevation models (DEM) and land use data of Zhenjiang City in 2000, 2010, and 2020, with a spatial resolution of 30 m. Vector data includes the administrative boundaries of Jiangsu Province and Zhenjiang City. DEM data comes from geospatial data clouds, while land use data comes from global land cover data (https://www.globeland30.org/). The vector data comes from the Alibaba Cloud visualization platform (https://datav.aliyun.com/portal/school/atlas/area_selecter). The conversion of vector data comes from the OSM data sharing platform (https://mapshaper.org/). In addition, referring to the existing land classification system in China [12] and combining with the actual situation of land use types in Zhenjiang City, land use types are divided into six categories: cultivated land, forest land, grassland, wetland, and construction land (Table 1).

Table 1 Required Data Source

Data requirements	Data sources	Purpose
Land use data	Globeland30 (https://www.globeland30.org/)	Identify and classify different types of land
30m DEM	Geospatial Data Cloud (https://www.gscloud.cn/)	Plot analysis
Vector data of Jiangsu Province and Zhenjiang City	1.Alibaba Cloud Visualization Platform (https://datav.aliyun.com/portal/school/atlas/area_selector) 2.OSM Data Sharing Platform (https://mapshaper.org/)	Create the administrative scope of Zhenjiang City

3.2 Analysis Methods

The methods used in this study include data collection, calculation of the transfer matrix, calculation of land use dynamics, and calculation of the standard deviation ellipse (Figure 2). Describe as follows:

1. Data collection: Download land use data from the Global Land Cover Data website for the three periods of 2000, 2010, and 2020, and extract them according to masks. 2. Calculate the transfer matrix: First, use ArcGIS to calculate the transferred land area based on the collected data, and then calculate the total area of various land use types. Then, calculate the change characteristics of land use, including the inflow and outflow, based on the transfer matrix formula. 3. Calculate the dynamic degree of land use: Obtain the land use transfer function through the ArcGIS grid to calculate the transfer amount of the fused land use type area. 4. Calculate the standard deviation ellipse: Use ArcGIS statistical analysis tools to select the field and perform descriptive statistics to obtain the standard deviation result.

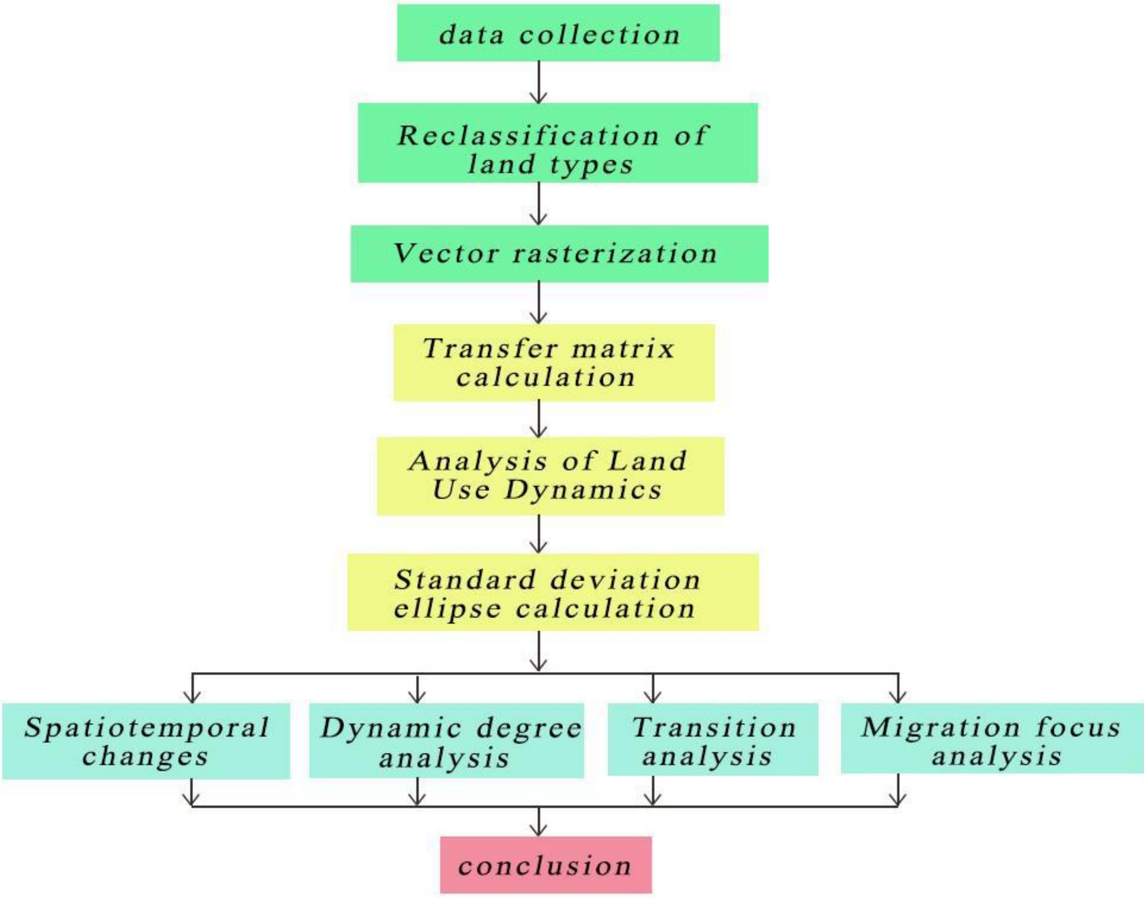

Fig.2 Technical Roadmap Flowchart

3.2.1 Land Use Transfer Matrix

The land use transfer matrix is the application of the Markov model in land use change, which can quantitatively illustrate the mutual transformation between land use types. This study is based on six types of land use data in Zhenjiang from 2000 to 2020. ArcGIS 10.8 software was used to superimpose and process this land use type data [13], calculating the area of transfer in and out of these six types of land use data in different years, and then obtaining the land use type transfer matrix. The formula is as follows:

$$S_{ij}=\begin{Bmatrix} S_{11} & S_{12} & \cdots & S_{1n} \\ S_{21} & S_{22} & \cdots & S_{2n} \\ & & & \\ S_{n1} & S_{n2} & \cdots & S_{nn} \end{Bmatrix} \quad (1)$$

In formula (1), n represents the land use types before and after the land transfer, S represents the land area, and i and j represent the land use types before and after the transfer, respectively (the values of i and j can be 1, 2,..., n).

3.2.2 Dynamic Analysis of Land Use

This study aims to analyze the dynamic changes, degree, and speed of land use types. A land use dynamic change model is used, and the transfer matrix method is combined to process land use data. The single land use dynamic degree [14] reflects the indicator of the speed and magnitude of changes in different land use types over a certain period of time. The formula is as follows:

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

In formula (2), K is the dynamic degree of land use type, Ua and Ub are the areas of a certain type of land in the early and late stages of research, respectively, and T represents the time period of research [15].

3.2.3 Standard Deviation Ellipse (SDE) Method

The Standard Deviation Ellipse (SDE) is a method of generating elliptical shapes by calculating the mean and standard deviation of a set of data points. The main parameters include centroid coordinates, azimuth angles, etc., which can intuitively describe the distribution pattern and direction of data points. This study used this method to calculate the centroid coordinates, major and minor axes, and azimuth angles of land use types in Zhenjiang City from 2000 to 2020 and analyzed the spatial distribution characteristics and changing trends of land use in the region. The calculation formula for the center of gravity coordinates is as follows [16]:

$$\bar{X}_w=\frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i},\quad \bar{Y}_w=\frac{\sum_{i=1}^{n} w_i y_i}{\sum_{i=1}^{n} w_i} \quad (3)$$

Where is the centroid coordinate, representing the relative position of geographic elements distributed in two-dimensional space; Wi is the weight value; (xi, yi) is the geometric center coordinate of the region.

IV. RESULT ANALYSIS

4. Spatial-temporal Variation Characteristics of Land Use Types

4.1.1 Time Variation of Land Use Area

Analysis shows that cropland, forests, water bodies, and construction land account for 64.30% -77.12%, 7.09% -8.00%, 7.46% -7.89%, and 7.24% -19.74% of the total land area, respectively, while grasslands and wetlands account for 0.09% -0.15% and 0.13% -0.25% of the total area (Table 2). From 2000 to 2020, the change in cropland area showed a decreasing trend year by year, from 2963.17 km^2 to 2470.52 km^2. The forest area showed a trend of first decreasing and then increasing, decreasing from 301.65km^2 to 272.44 km^2, and then increasing to 307.54 km^2. The grassland area has been increasing year by year, from 3.34 km^2 to 5.59 km^2. The trend of wetland area change shows a decreasing and then increasing trend, with 9.49 km^2 first decreasing to 5.13 km^2, and then increasing to 7.23 km^2. The change in water area shows a trend of first increasing and then decreasing, from 286.64 km^2 to 303.32 km^2, and then decreasing to 293.19 km^2. The change in construction land area has been increasing year by year, from 278.13 km^2 to 758.33 km^2.

Table 2 Changes in Land Use Type Area in Zhenjiang City from 2000 to 2020

Land-use type	2000		2010		2020	
	Area/ km^2	Ratio/%	Area/ km^2	Ratio/%	Area/ km^2	Ratio/%
Cropland	2963.17	77.12%	2893.81	75.31%	2470.52	64.30%
Forest	301.65	7.85%	272.44	7.09%	307.54	8.00%
Grassland	3.34	0.09%	4.35	0.11%	5.59	0.15%
Wetland	9.49	0.25%	5.13	0.13%	7.23	0.19%
Water body	286.64	7.46%	303.32	7.89%	293.19	7.63%
Construction land	278.13	7.24%	363.35	9.46%	758.33	19.74%

4.1.2 Spatial Changes in Land Use Types

Analysis shows that the cropland area in Zhenjiang has been continuously decreasing from 2000 to 2020. The area of northern forests decreased between 2000 and 2010, but increased in the following decade. Wetlands are concentrated in Dantu District of Zhenjiang and the western part of Jurong City. The wetland area showed a decreasing trend from 2000 to 2010, but an increasing trend from 2010 to 2020. The water bodies are in the form of rivers, distributed in the northern parts of Zhenrunzhou District, Jingkou District, and Yangzhong City, with no significant changes in area. The proportion of construction land continues to expand, mainly concentrated in the northern parts of Danyang City, Runzhou District, and Jingkou District (Figure 3).

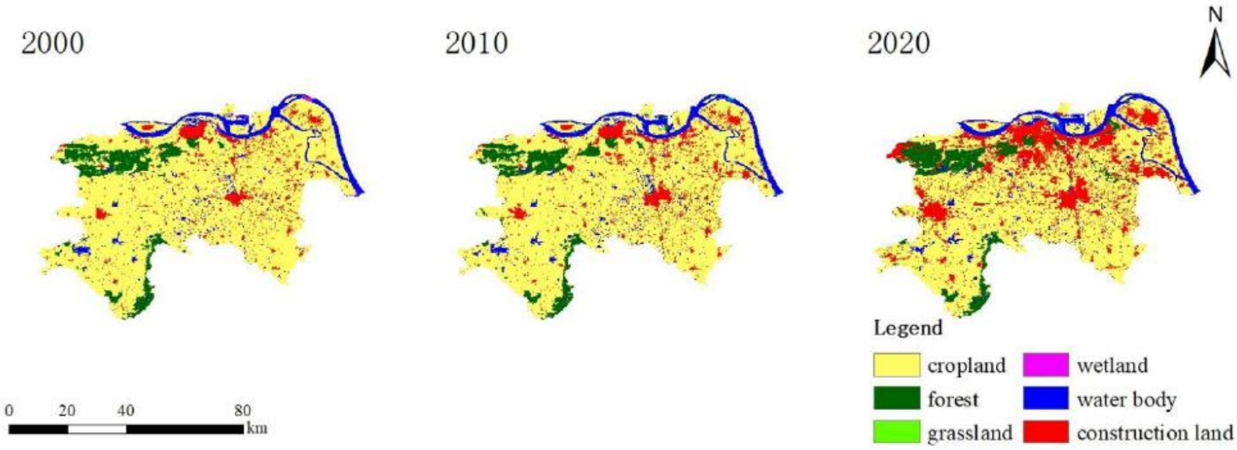

Fig.3 Land Use Changes in Zhenjiang City in the Past Two Decades

4.2 Analysis of Land Use Transfer

Analysis shows that from 2000 to 2010, the grassland was stable, with relatively low levels of outflow and inflow. The main transfer of cropland is construction land, forests, and water bodies, with specific transfer amounts of 117.73 km^2, 22.22 km^2, and 30.2 km^2, respectively. The construction land is transferred from cropland, with an area of 117.73 km^2. The main transfer of forests is cropland and water bodies, with specific transfer amounts of 39.92 km^2 and 12.91 km^2, respectively. Wetlands are also quite stable, with relatively small inflows and outflows. The water bodies are transferred from cropland and forests, with transfer amounts of 30.2 km^2 and 12.91 km^2, respectively (Table 3).

Table 3 Land Transfer Matrix of Zhenjiang City from 2000 to 2010(km^2)

Land-use type	Grassland	Cropland	Construction	Forest	Wetland	Water body
Grassland	2.54	0.3	0.03	0.27	0.05	0.16
Cropland	0.97	2791.41	117.73	22.22	0.64	30.2
Construction	0.07	33.13	243.3	0.26	0.01	1.37
Forest	0.27	39.92	0.34	248.2	0	12.91
Wetland	0.34	3.48	0.29	0.3	2.82	2.26
Water body	0.17	25.57	1.66	1.19	1.62	256.44

Analysis shows that from 2010 to 2020, the amount of grassland transfer was relatively small (Table 4), mainly from cropland, with a transfer amount of 2.17 km^2. The main transfer of cropland is construction land, forests, and water bodies, with specific transfer amounts of 408.76 km^2, 57.88 km^2, and 36.14 km^2. The amount of forest transfer is relatively small, mainly from cultivated land, with a transfer volume of 57.88 km^2. The outflow and inflow of wetlands are relatively small, and the amount of wetland conversion into grassland, construction land, and forest, as well as the amount of grassland, construction land, and forest conversion into wetlands, are all zero. The main transfer of water bodies is cropland, with a specific transfer volume of 45.01 km^2.

Table 4 Land Use Transfer Matrix of Zhenjiang City from 2010 to 2020 (km^2)

Land-use type	Grassland	Cropland	Construction	Forest	Wetland	Water body
Grassland	1.84	0.83	0.55	0.61	0	0.52
Cropland	2.17	2383.75	408.76	57.88	4.1	36.14
Construction	0.79	30.16	329.49	1.22	0	1.64
Forest	0.55	8.93	13.22	246.23	0	3.28
Wetland	0	0.85	0	0	0.7	3.57
Water body	0.25	45.01	6.2	1.38	2.41	247.35

Analysis shows that there were a total of 29 types of land use changes in Zhenjiang from 2000 to 2010, mainly consisting of cropland, construction land, and forests. The proportion of conversion between various land uses was relatively small, forming a point-like distribution. The concentrated areas of conversion are Dantu District, Danzhou City, Jingkou District, and Jurong City, mainly for the conversion of cropland to construction land, forests to cropland, and cropland to water bodies. These areas have vast cropland areas and relatively developed agriculture [17], which are greatly affected by human activities (Figure 4, Figure 6).

According to the supporting data, the Land and Resources Bureau of Yangzhong City agreed to relinquish a state-owned land use right of Yangzhong Sanmao Electrical Materials Co., Ltd. in 2010. The land was originally a water body but was later approved by the Provincial People's Government to be expropriated as state-owned construction land [18], indicating that some of the land use transfer in the area came from such human activities, thus presenting as water bodies being converted into construction land. In addition, the northwest of Zhenjiang is characterized by low mountains and hills. These areas have fertile soil and good drainage, providing favorable site conditions for forest growth. Therefore, there are a large number of forests distributed, such as Baohua Mountain National Forest Park, which has rich biodiversity and unique natural landscapes [19]. It is an important area for forest protection in the northwest of Jurong City. With the acceleration of urbanization in Jurong City, the demand for urban construction land continues to increase, and some forests have been transformed into urban construction land, such as residential and commercial areas.

Analysis shows that there were a total of 25 types of land use changes in Zhenjiang from 2010 to 2020, mainly construction land, cropland, and forests. The conversion between each type of land use was relatively frequent, with larger changes compared to the previous decade, showing a distribution pattern of patchy and dotted. The main manifestation is the conversion of cropland to construction land, forests, and water bodies, and the conversion of forests to construction land. The concentrated areas of conversion are Jurong City, Runzhou District, Danyang City, and Jingkou District. Among them, with the acceleration of urbanization, the demand for urban construction land in Runzhou District continues to increase. To meet this demand, some cropland has been requisitioned and converted into urban construction land, including different types of urban construction land for residential, commercial, industrial, etc. [20]. The northeastern part of Jingkou District has sufficient precipitation, suitable temperature, and fertile soil, which makes it easier for cropland in the area to be converted into forests (Figure 5, Figure 6).

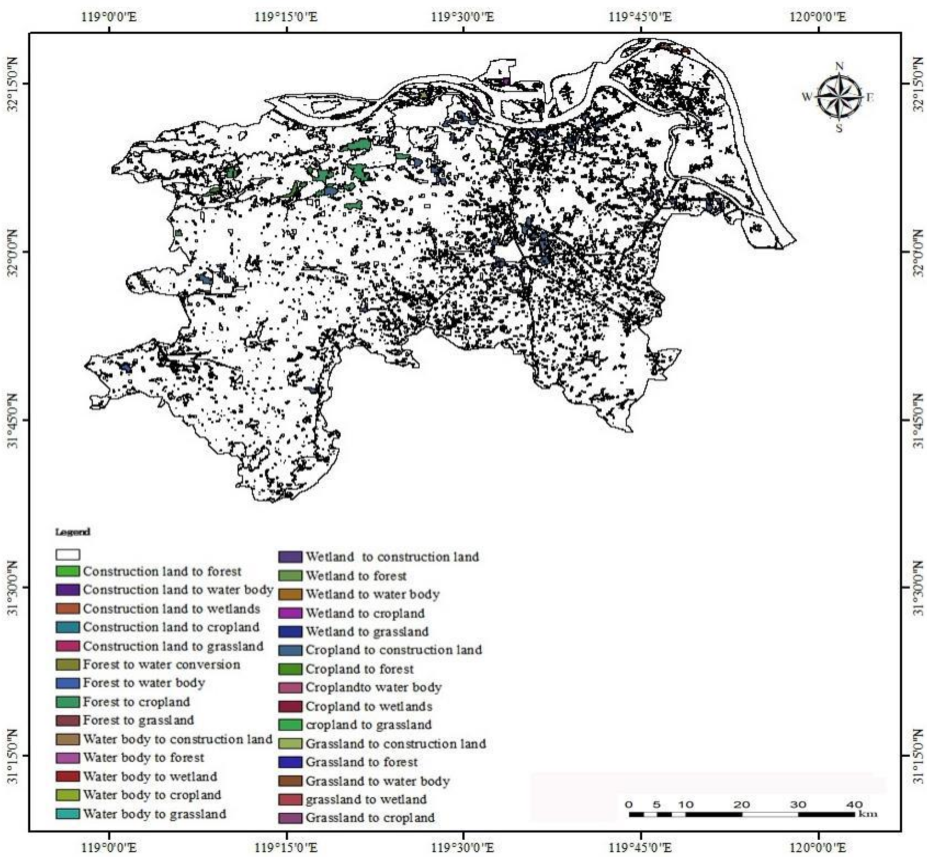

Fig .4 Transfer Maps of Different Land Use Types from 2000 to 2010

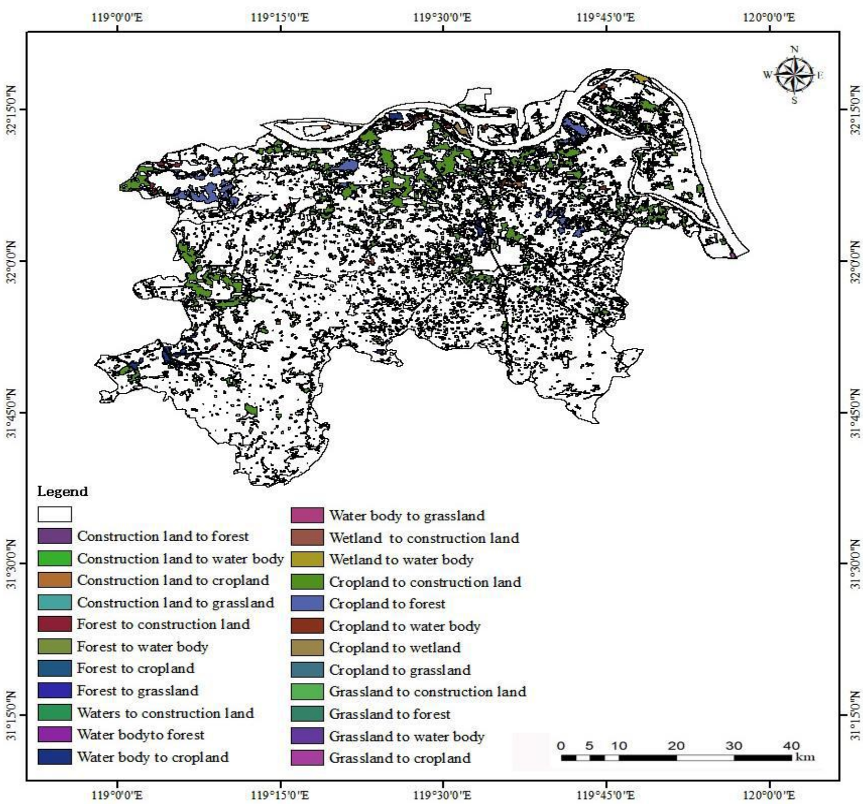

Fig.5 Transfer Map of Different Land Use Types from 2010 to 2020

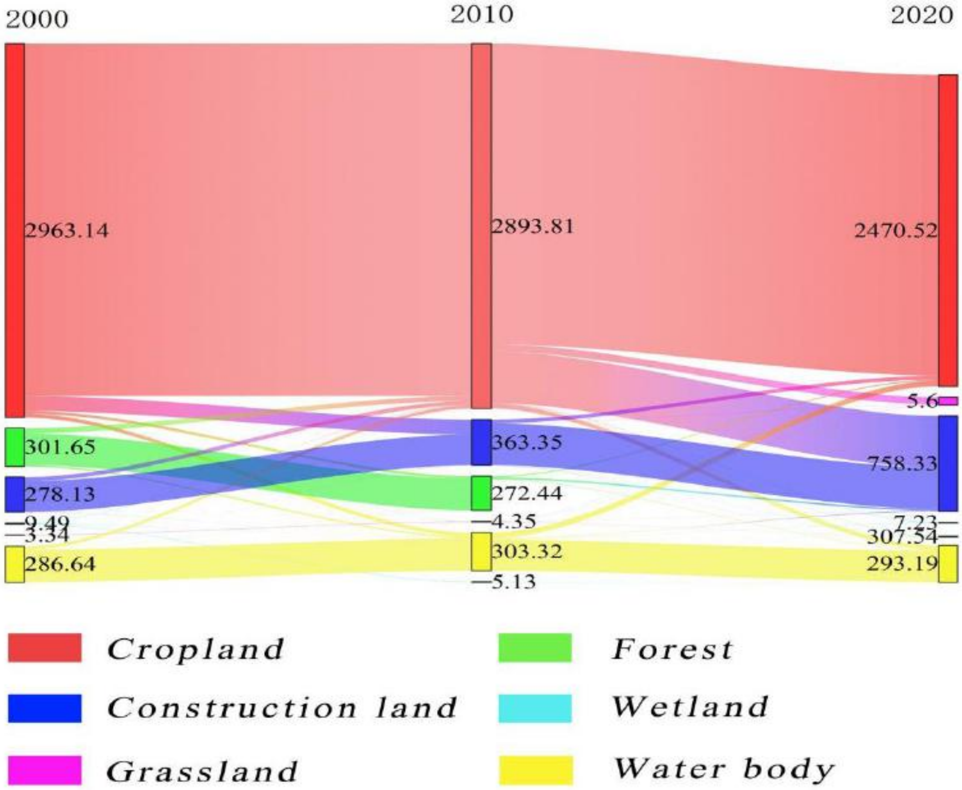

Fig.6: Sankey Map of Land Use Transfer from 2000 to 2020

4.3 Dynamic Degree Analysis

There are significant differences in the dynamic degree of single land use in Zhenjiang (Table 5, Figure 7). From 2000 to 2010, the areas of cropland, forests, and wetlands decreased, with dynamic degrees of -0.23%, -0.97%, and -4.59%, respectively. The dynamic degrees of grassland, water bodies, and construction land are all positive, at 3.02%, 0.58%, and 3.06%, respectively, indicating an increase in the area of these three land uses.

From 2010 to 2020, the expansion of construction land area was relatively large, with a dynamic attitude value of 10.87%, indicating that the urban development of Zhenjiang has been rapid during this decade, with significant improvements in both scale and speed. The dynamic degrees of cropland and water bodies are negative, with values of -1.46% and -0.33%, respectively. The dynamic degrees of forests, grasslands, and wetlands are positive, with values of 1.29%, 2.85%, and 4.09%, respectively.

Overall, from 2000 to 2020, the dynamic degree of construction land was 17.27%, forests were 0.20%, grasslands were 6.74%, water bodies were 0.23%, and cropland and wetlands were both negative values, at -1.66% and -2.38%, respectively.

Table 5 Comparison of Dynamic Degree of Single Land Use in Different Periods

Type		2000-2010	2010-2020	2000-2020
Dynamic degree of single land use/%	Cropland	-0.23	-1.46	-1.66
	Forest	-0.97	1.29	0.20
	Grassland	3.02	2.85	6.74
	Wetland	-4.59	4.09	-2.38
	Waters	0.58	-0.33	0.23
	Construction	3.06	10.87	17.27

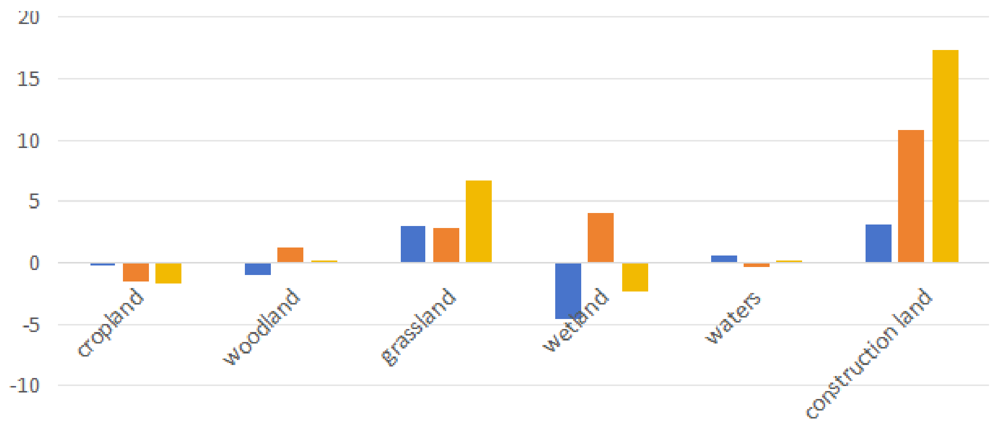

Fig.7 Comparison of Dynamic Degree of Single Land Use in Different Periods

In addition, based on the comprehensive dynamic degree of land use in Zhenjiang from 2000 to 2020 (Table 6, Figure 8), the comprehensive dynamic degree of land use in the first ten years was 0.27%, the second ten years was 1.13%, and the overall annual comprehensive dynamic degree was 1.29%. Analysis shows that the degree of land use was relatively low from 2000 to 2010. There is a clear trend of change in the last decade compared to the previous decade. Overall, the comprehensive dynamic degree of land use from 2000 to 2020 has gradually increased, and the changes have shown a clear upward trend.

Table 6 Comprehensive Dynamic Degree of Land Use in Different Time Periods

Serial Number	Time	Comprehensive dynamic diagram/%
1	2000-2010	0.27
2	2010-2020	1.13
3	2000-2020	1.29

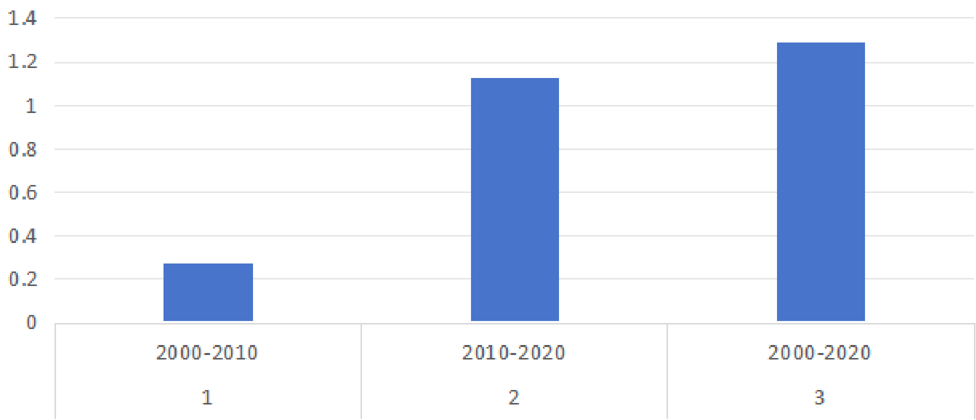

Fig.8 Comprehensive Dynamic Degree of Land Use in Different Periods

4.4 Standard Deviation Elliptical Analysis

To explore the changes in the spatial pattern of land use, the standard deviation and center of gravity migration trajectory of construction land ellipses in different periods of the study area were plotted, and the changes in the spatial pattern of construction land from 2000 to 2020 were analyzed (Figure 9, Table 7).

From the center of gravity coordinates, the distribution of the center of gravity of construction land from 2000 to 2020 was between (119° 33′ 32.48" to 119° 38′ 14.75", 32° 00 ′ 30.47" to 32° 09′ 19.15"), located in the northeast direction of Zhenjiang, indicating that there have been significant changes in construction land in the east and north in the past two decades.

From the perspective of the direction of center of gravity migration, the center of gravity of construction land shifted towards the northeast from 2000 to 2010 and towards the southwest from 2010 to 2020. Overall, in the past two decades, the focus of construction land has shifted from northeast to southwest, mainly in the central area of Dantu District.

From the perspective of the long axis direction, the construction land decreased from 28.29km in 2000 to 25.04km in 2010, and then increased to 27.59km in 2020, showing a trend of first decreasing and then increasing. This indicates that during this period, the construction land showed a phenomenon of first diverging and then converging in the "northeast southwest" direction, and the construction land area showed a trend of first decreasing and then increasing in the "northeast southwest" direction.

From the perspective of the short axis, the construction land increased from 17.81km in 2000 to 18.20km in 2020, showing an increasing trend. This indicates that the construction land during this period diverged in the "northeast southwest" direction, and the construction land area showed an increasing trend.

From the perspective of azimuth changes, there has been a trend of first decreasing and then increasing in the past two decades, decreasing from 61.25° in 2000 to 57.71° in 2010, and then increasing to 70.36° in 2020. This indicates that the construction land area in Zhenjiang has been decreasing before 2010 and has increased between 2010 and 2020.

Table 7 SDE Parameters of Construction Land from 2000 to 2020

Year	Barycentric coordinate		Long axis/km	Short axis/km	Azimuth angle/°
	Longitude	Latitude			
2000	119°33′32.48"	32°08′57.36"	28.29	17.81	61.29
2010	119°38′14.75"	32°09′19.15"	25.04	17.09	57.71
2020	119°35′32.24"	32°00′30.47"	27.59	18.2	70.36

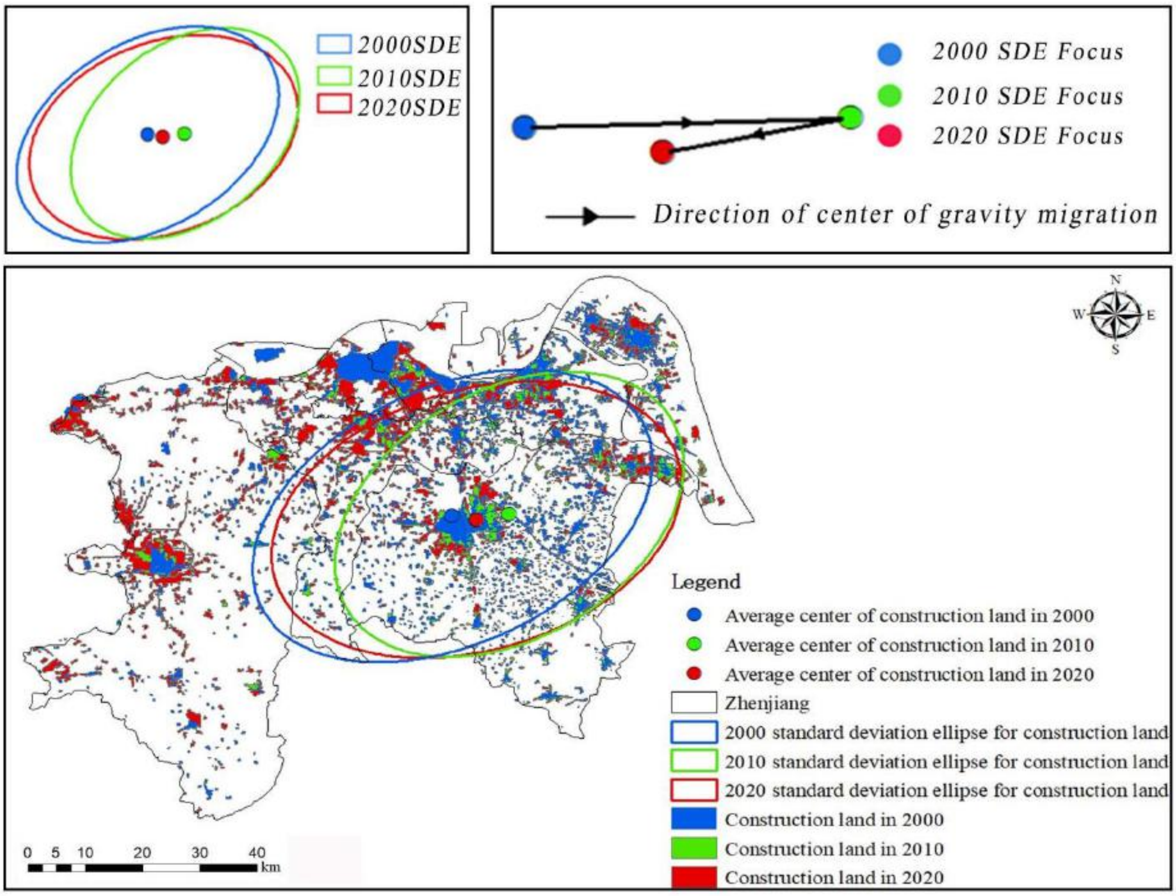

Fig.9 SDE and Center of Gravity Migration Trajectory of Construction Land from 2000 to 2010

V. CONCLUSION

This study uses the land use data of Zhenjiang City in 2000, 2010, and 2020 as the benchmark and adopts the methods of transition matrix, dynamic degree analysis, and SDE to analyze the spatiotemporal changes of land types from 2000 to 2020. The results indicate that land use types are divided into cropland, forests, grasslands, wetlands, water bodies, and construction land. Among them, cropland, construction land, forests, and water bodies are the main areas, while grasslands and wetlands account for a relatively small proportion. Their specific areas are cropland>construction land>forests>water bodies>wetlands>grasslands.

In terms of changes, the decrease in cropland area is the most significant, while the increase in construction land is the largest, indicating that the urban development of Zhenjiang is rapid, and its development speed and scale have greatly improved [21]. On the other hand, it indicates that during this period, the land in Zhenjiang has been greatly affected by human activities, and the ecological environment quality has been greatly impacted, posing significant challenges and pressures to the environment. In terms of spatial changes, the expansion of construction land is concentrated in the northern and central regions, indicating that the northern and central regions of Zhenjiang are in an accelerated stage of urbanization. Urban infrastructure, public service facilities, etc. are constantly improving, attracting more population and enterprises to settle in, thereby promoting the expansion of construction land. In addition, the continuous decrease in cropland area in the past two decades indicates that with the economic development of Zhenjiang and the acceleration of urbanization and industrialization processes, the demand for construction land is constantly increasing. This has led to the conversion of some cropland into urban construction land, industrial land, etc., resulting in a continuous decrease in cropland area. The area of wetlands and forests first decreased and then increased, indicating that from 2000 to 2010, due to a lack of sufficient ecological protection awareness and to meet the needs of economic development and population growth, the wetland resources in Zhenjiang were damaged and occupied to a certain extent during the acceleration of urbanization, industrialization, and other processes. Some wetlands were converted into construction land or other uses. The expansion of land in the process of urbanization has also led to the occupation of some forests, thereby reducing the forest area.

In terms of land use transfer, the area of cropland transferred to construction land was the largest from 2000 to 2010, indicating that with the rapid development of Zhenjiang's economy, higher requirements have been put forward for the utilization of land resources, and the occupation and impact of cropland are the most severe. The water bodies are transferred from cropland, indicating that Zhenjiang has increased its efforts to protect and restore water resources. By implementing a series of ecological protection measures, such as establishing wetland protection areas and restoring damaged water ecosystems, the water area has been effectively increased. From 2010 to 2020, the main circulation of cropland was forests and water bodies, indicating that Zhenjiang increased its efforts to protect the ecological environment and water resources during this period, and implemented a series of greening projects. These projects include returning farmland to forests, afforestation, etc., aimed at increasing forest coverage and improving the ecological environment.

In terms of land use dynamics, the comprehensive land use dynamics showed an increasing trend from 2000 to 2020, reaching a maximum value of 1.13% from 2010 to 2020, indicating that the transformation of land use types was most intense from 2010 to 2020. This indicates that there has been frequent conversion between land use types during this period, and significant changes have occurred in land use patterns due to factors such as economic development and population growth. Among them, the single land use dynamics of wetlands and construction land were the highest during this period, reaching peak values of 4.09% and 10.87%, respectively. On the one hand, it indicates that wetlands have suffered severe degradation during this period due to excessive development and utilization of wetland resources caused by human activities such as urbanization and industrialization. On the other hand, it indicates that with the growth of population and economic development, the demand for construction land in cities continues to increase, leading to the continuous expansion of construction land area.

In the past two decades, the center of gravity of construction land has undergone significant changes, shifting from northeast to southwest. On the one hand, it indicates that the economic vitality and development potential of the Southwest region are gradually increasing, attracting more investment and population inflows, and thereby promoting the expansion of construction land in the region. On the other hand, it also reflects the continuous optimization of urban spatial layout in the process of urbanization in Zhenjiang in order to meet the new needs of economic and social development and promote the city's development towards a more balanced and sustainable direction.

ACKNOWLEDGEMENTS

The author is grateful for the research grants given to Ruei-Yuan Wang from GDUPT Talents Recruitment, Peoples R China under Grant No.2019rc098, and Academic Affairs in GDUPT for Goal Problem-Oriented Teaching Innovation and Practice Project Grant No.701-234660.

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