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Assessment of Carbon Reserves in Nanchang City, Jiangxi Province, Using the InVEST Model

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Abstract— *This study depends on the dynamic index of land use change and land transfer matrix, as well as the carbon module in the InVEST model. The features of land use change and carbon reserve change in Nanchang city from 2001 to 2021 were investigated, and the influence of land use change on carbon reserve was identified. The results show that, from 2001 to 2021, the area of cultivated land, water area, grassland, and bare land in Nanchang City decreased while the area of construction land and forest land increased. Under the influence of land use changes, the high-value areas of carbon reserves are mostly distributed in forest areas, including the northwest and southeast parts of Nanchang, whereas the low-value areas are mostly distributed in urban construction areas, including the central part of Nanchang, which is consistent with the current situation of urban land types. Overall, the carbon reserves of Nanchang City decreased from 2001 to 2021, primarily due to the decrease of cultivated land and the increase of construction land.*

Keywords*— *land use change, carbon reserves, InVEST model, Nanchang City.

I. INTRODUCTION

The growth and collapse of ecology corresponds to the rise and fall of civilization. Since the CPC's 19th National Congress, the whole country has earnestly implemented the Party's vision for ecological civilization construction and promoted sustainable development to the pinnacle of green development (Cai, 2000). According to studies has a significant impact on ecosystem carbon storage capacity because it affects both vegetation and soil carbon stocks. Land use change is an essential indicator of human activities and directly affects the terrestrial ecosystem carbon reserves(Zhu et al., 2022). It is an important factor influencing the change of carbon stocks in the whole region (Fang et al., 2015). The study of land use change is of great significance to the sustainable development of regional economy (Zong and Cao, 2020), the coordinated development of ecological economy (Liu et al., 2021), and the sustainable use of land (Xu et al., 2009). Regional carbon emissions have attracted significant attention in the context of sustainable development.

As the core area of the construction of Jiangxi Province and Poyang Lake ecological economic zone, Nanchang city has a large demand for construction land, coupled with the frequent extensive use of land, resulting in the shortage of available arable land resources and great pressure on the urban ecological environment. Therefore, this study, from the perspective of land use change, as the research area of Nanchang, Jiangxi province, applying the InVEST model, combined with the dynamic degree index of land use change and land transfer matrix, discusses the spatial and temporal change of carbon reserves in 2001-2021 and aims to reveal the influence of land use change on carbon reserves, for regional land use planning and carbon management, which has important reference value, in order to provide theoretical support for urban practice of green development concept.

II. STUDY AREA

Nanchang city is located in the north central part of Jiangxi Province, China, between east longitude 115 27 '-116 35' and north latitude 28 10 '-29 11', which belongs to the subtropical monsoon humid climate (Figure 1). The terrain of the territory is "three rivers with five lakes, control Manjing and lead ouyue," that is, the southeast terrain is flat, northwest hills, ups and downs; Ganjiang River, Fuhe River downstream, the southwest bank of Poyang Lake, abundant rainfall.

Nanchang is the capital of Jiangxi Province, the earliest aviation industry base, an important comprehensive transportation hub and photovoltaic industry base in China, and a world-class photovoltaic industry base. It is one of the important members of the Yangtze River economic belt, urban agglomeration in the middle reaches of the Yangtze River, and in the "Belt and Road" initiative node, is the link between the Midwest and the southeast coast important traffic corridor, and with the nine integrations, urban agglomeration in the middle reaches of the Yangtze River, the implementation of the river district policy, urban construction land expansion, and land use changed significantly.

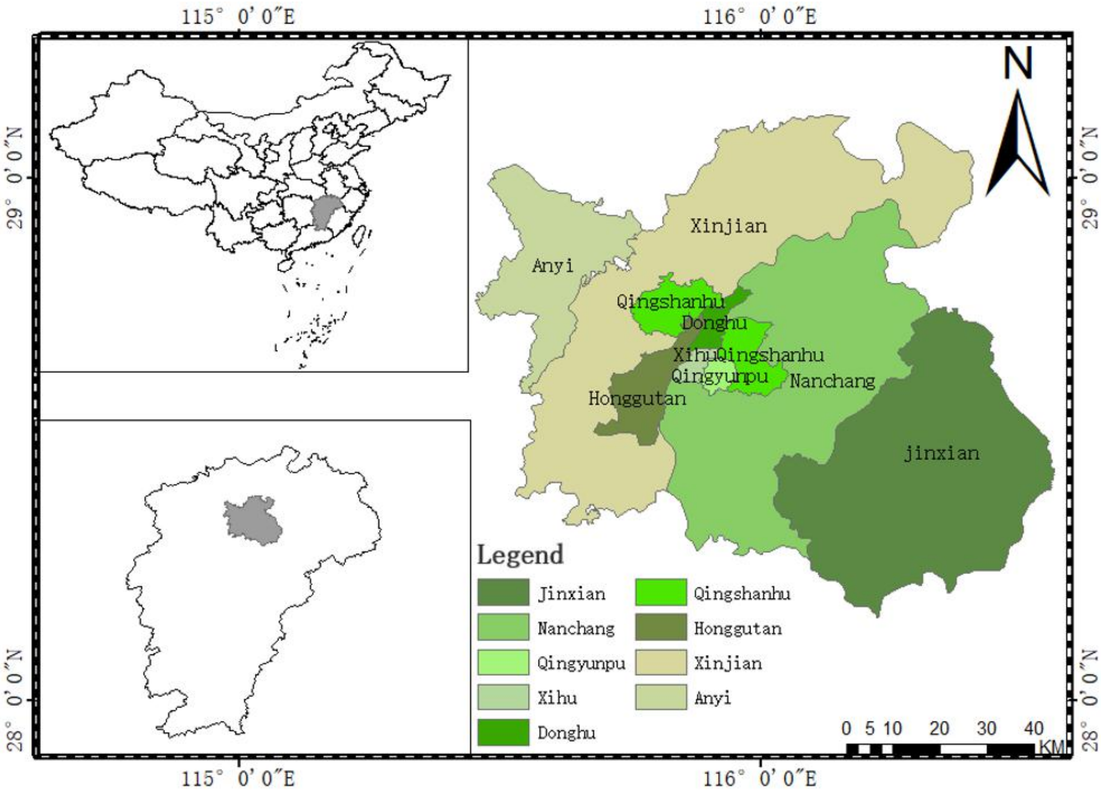


Fig.1 Map of administrative division of Nanchang City

III. METHODOLOGY

3.1 Data Collection

This study's data sources are as follows:

1. The land use data of Nanchang city in 2001 and 2021 are derived from Yang & Huang (2022), that is, the 30 m annual land cover datasets and its dynamics in China from 1990 to 2021 (1.0.0), (Zenodo, https://doi.org/10.5281/zenodo.5816591).
2. The spatial resolution of land cover data is 30 m, including nine types of land for cropland, forest, shrubs, water area, grassland, bare land, and buildings.
3. Carbon bank data: consult the literature and sort out the carbon density data of above-ground and

underground roots, soil, and dead organic matter of various urban land types.

4. Administrative boundary data originated from the Resource and Environment Data Center of the Chinese Academy of Sciences, and extracted vector data from the study area.

3.2 Methods

3.2.1 Land Use Change

Land use dynamic degree: describe the intensity of land use change in a certain area, reflecting the difference in the change rate of different land use types in the region (Zhu and Wang, 2013; Lai and Wen, 2022). Formula for calculating a single land-use dynamic degree:

$$D=\frac{Ub-Ua}{Ua}\times\frac{1}{T}\times 100\% \qquad (1)$$

Where D is the dynamic degree of a land use type during the analysis period; Ua and U_b represent the area of a land use type at the beginning and end of the analysis period; T is the long analysis period.

Land use transfer matrix: using the matrix form to represent the interconversion area between different land classes effectively analyzes the internal transfer characteristics and pattern changes of land use classification in the research area and reflects the transformation between various land categories, including the direction, area, and development trend of transfer.

In Table 1, two time points T_1 and T_2 are located in rows and columns, respectively, and they indicate the current land cover in the study area at time points T_1 and T_2. P_{ij} represents the area converted from i land use type to land use type j during T_1-T_2, and P_{ii} indicates the area where land of type I was not converted to other types of land during the study period. P_{i+} represents the total area of land of type i at the study start time T_1, and P_{+j} represents the total area of land of type j at the end of the study time T_2. P_{i+} -P_{ii} refers to the area or area percentage of type I land decrease during the study period T_1-T_2; similarly, P_{+j}- P_{jj} refers to the area or percentage area of type j land increase during the study period T_1-T_2 (Liu and Zhu, 2010).

Table 1 Land use transfer matrix

		T_2				P_{i+}	Decrease
		A_1	A_2	...	A_n		
T_1	A_1	P_{11}	P_{12}	...	P_{1n}	P_{1+}	P_{1+}-P_{11}
	A_2	P_{21}	P_{22}	...	P_{2n}	P_{2+}	P_{2+}-P_{22}
	...	...	...	...	...	...	...
	A_n	P_{n1}	P_{n2}	...	P_{nn}	P_{n+}	P_{n+}-P_{nn}
P_{+j}		P_{+1}	P_{+2}	...	P_{+n}	1	
Newly increased		P_{+1}-P_{11}	P_{+2}-P_{22}	...	P_{+n}-P_{nn}		

3.2.2 Carbon Reserves

InVEST The carbon module in the model divides the ecosystem carbon reserves into four basic carbon pools, namely, aboveground biological carbon, underground biological carbon, soil carbon, and dead organic carbon. The module uses socio-economic and natural data under current or future scenarios as inputs to output the spatial distribution and evolution trend of carbon stocks under certain scenarios (zhang, 2016). Above ground biomass includes all surviving plant materials above soil, such as tree trunks, branches, leaves, bark, etc. with the average value of carbon reserves per unit area around 0 to 20 cm above the surface; underground biomass includes the living root system of the plants with average carbon reserves per unit area around 0 to 20 cm below the surface; soil carbon reservoirs are usually limited to organic carbon from mineral soil but also organic soil, which is the average value of carbon reserves per unit area around 20 to 100 cm below the surface; dead organic matter includes litter, inverted or standing dead trees. The formula is as follows:

$$C = C_{above}+C_{below}+C_{soil}+C_{dead} \qquad (2)$$

Where C is the total carbon storage of the terrestrial ecosystem, C_{above} is the aboveground carbon storage, C_{below} is the underground carbon storage, C_{soil} is the soil carbon storage, and C_{dead} is the carbon storage of dead organic matter.

The data required for model operation mainly includes land use/cover type data and carbon storage in each carbon bank to calculate the total amount of carbon storage in the ecosystem. Carbon density data is an important factor for the InVEST model to calculate the carbon storage in the ecosystem, and the carbon density is the carbon storage per unit area. In this paper, the research results obtained in the same or adjacent regions are integrated (Table 2). The average carbon storage per unit area is expressed by Mg/hm^2.

Table 2 Carbon density of different land use types in Nanchang city (Mg / hm^2)

Type	Above-ground carbon density	Underground carbon density	Soil carbon carbon density	Litter carbon carbon density
Cropland	4.7	0	54.5	0
Forest land	60.17	12.64	68.79	4.4
Grassland	1.52	3.11	9.99	1.99
Waters	2.93	0.81	0.5	0
Bare ground	0	0	0	0
Building	0	0	0	0

IV. RESULTS AND ANALYSIS

4.1 Characteristics of Land Use Change

This paper, based on 30 m× 30 m resolution of Nanchang land use grid data, used the ArcGIS 10.1 spatial analysis method to extract the area of the six land use types in 2001, 2011, and 2021, namely cropland, forestland, grassland, water area, bare land, and building land (Figure 3), establish the land use transfer matrix, analyze the scale of the Nanchang land type and transfer direction, and form an intuitive comparison.

In terms of spatial distribution, between 2001 and 2021, the general land use distribution pattern in Nanchang city has not changed greatly. The land use type is mainly cropland and building land, with a broad water area and numerous water systems and rivers in the territory. The cropland land is distributed in most areas outside the water area, and the building land is increasing, concentrated in the city center and rivers along the Ganjiang River. The water is mainly distributed in the east and north, namely Poyang Lake; in the middle, the Ganjiang River passes into cropland land in 20 years. Most of the forestland is concentrated in the northwest and southeast, consistent with the northwest hilly terrain; the grassland is distributed in the forestland, and most of the secondary vegetation formed after the destruction of forest resources. Overall, the change range of forestland and grassland area is small. Most of the bare land is distributed near the water, indicating that the bare land originates from the periodic fluctuation of the water area.

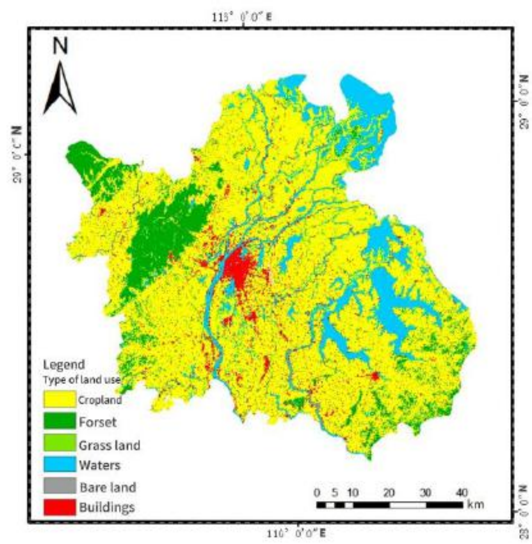
According to Table 3, the area changes of cropland, grassland, water area, and bare land were consistent, and the four types of land use decreased; the area of the two land use types of forest land and buildings land increased.

The area of cropland decreased the most in 2001 and 2021, with 4864.8771 km^2 and 4818.2337 km^2 respectively. In the past 20 years, the cropland area was less than 364.829 km^2, and the area decreased by 7.49%, making it the largest land type in Nanchang.

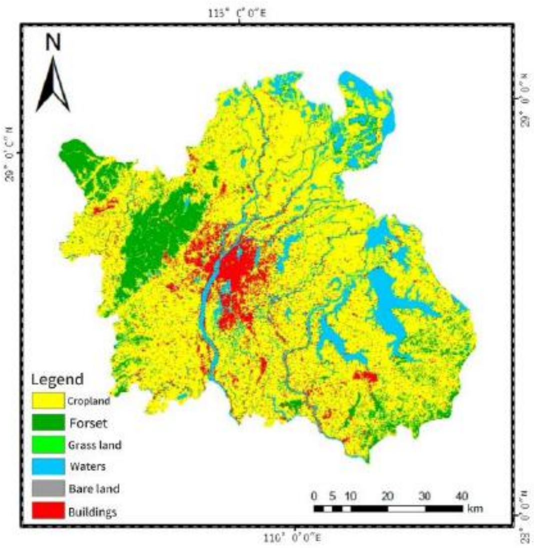
The area of forest land was first reduced and then increased. In 2001 and 2021, the area was 806.7087 km^2 and 891.9414 km^2 respectively, and the overall increase was 85.233 km^2 in the past 20 years, an increase of 11.03% compared with 2011, indicating that Nanchang pays attention to the protection of the ecological environment in the later development process.

The area of building land has increased the most in the past 20 years. In 2021, the area of buildings land is 749.1285 km^2, with an average annual rate of 4.454%, an increase of 90.48% compared with 2001. Building land has become a major advantage of land types in Nanchang.

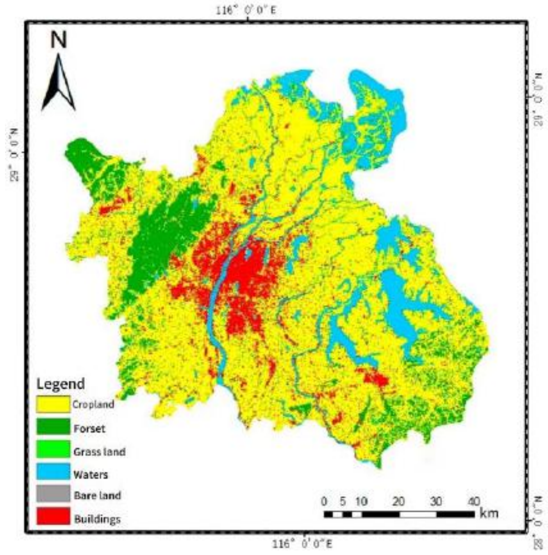
The water area has decreased in the past 20 years; in 2001 and 2021, 1106.1765 km^2 and 1044.748 km^2 respectively, only reducing 61.4286 km^2, 5.55% less than that in 2001. If it continues to decrease, it will be difficult to meet the needs of human production and life, causing bad effects.



(a) Land use distribution in 2001



(b) Land use distribution in 2011



(c) Land use distribution in 2021

Fig.3 Land use distribution map

.The area of grassland in 2001 and 2021 was 9.9414km^2 and 8.7381km^2 respectively, and the grassland area decreased by 7.6104km^2 in the past 20 years. Meanwhile, the bare land has changed greatly, with the area in 2001 being 10.4787km^2 and 3.2787km^2 in 2021, and the area decreased by 7.2km^2. In comparison, grass changes more dynamic attitudes than bare land.

The four types of land use with reduced area decreased from large to small: cropland>water>grassland>bare land, and the two types of land use with increased area increased from large to small: Building land>forest land, building land increased at an average annual rate of 4.524%.

The land use data of Nanchang was analyzed using ArcGIS 10.1, and the land use transfer matrix was extracted after Excel treatment. According to Table 4 and Table 5, between 2001 and 2021, the building land increased rapidly, mainly derived from the transformation of cropland land, indicating the accelerated process of urbanization. Between 20 years, the building land area has increased from 393.2937km^2 in 2001 to 749.1285km^2 in 2021, increasing at an annual average 17.79km^2 rates. Through calculation, a total of 322.8453km^2 cropland has been converted into building land, accounting for 90.73%

of the newly added building land. It can be seen that cropland land is the main source of building land expansion, and Nanchang city has developed remarkable urban expansion in recent years. The change in water area is small; in 20 years, the area decreased by 61.4285km^2, mainly transformed into crop land and building land, indicating that urban expansion accelerates land development and utilization. The bare land is distributed near the water area. With the transformation of the water area, the bare land area decreases continuously, and the area drops from 10.4787km^2 to 3.2787km^2. On the whole, the decrease of the area of cropland, grassland, water area, and bare land is structurally related to the increase of the area of forest land and building land.

Table 3 Land use area and attitude in Nanchang during 2001-2021 (%)

Year Land type	2001 area/km^2	2011 area/km^2	2021 area/km^2	2001-2021 area/km^2	Dynamics degree (%)
Cropland	4864.8771	4818.2337	4500.049	-364.829	-0.375
Forest	806.7087	803.3562	891.9414	85.233	0.528
Grassland	9.9414	8.7381	2.331	-7.6104	-3.828
Waters	1106.1765	979.3674	1044.748	-61.4286	-0.278
Bare land	10.4787	5.8095	3.2787	-7.2	-3.436
Buildings	393.2937	575.9712	749.1285	355.835	4.524

Table 4 Land Use Transfer Matrix of Nanchang City from 2001 to 2011 (unit: km^2)

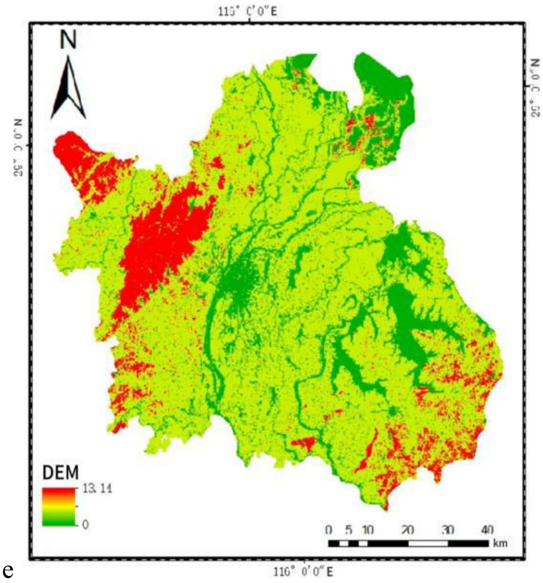
Type	Cropland	Forest	Grassland	Waters	Bare land	Buildings	Total
Cropland	4516.8408	95.8914	2.016	86.5395	0.1215	163.4679	4864.8771
Forest	111.5739	688.4982	0.3978	2.0727	0	4.1661	806.7087
Grassland	1.3986	0.0864	3.0195	2.6307	0.774	2.0619	9.9414
Waters	187.6212	18.8784	1.5147	876.5028	1.5282	20.1312	1106.1765
Bare land	0.4158	0	1.7865	3.4965	3.4056	1.3743	10.4787
Buildings	0.3834	0.0018	0.0036	8.1252	0.0099	384.7698	393.2937
Total	4818.234	803.3562	8.7381	979.3674	5.8095	575.9712	

Table 5 Land Use Transfer Matrix of Nanchang City from 2011 to 2021 (unit: km^2)

Type	Cropland	Forest	Grassland	Waters	Bare land	Buildings	Total
Cropland	4334.9454	163.7856	0.2079	157.8771	0.036	161.3817	4818.234
Forest	64.7244	727.6842	0.0017	8.0118	0	2.9241	803.3562
Grassland	2.7324	0.2448	1.0791	1.746	0.504	2.4318	8.7381
Waters	96.6348	0.225	0.3357	866.3859	0.8379	14.9481	979.3674
Bare land	0.5112	0.0018	0.6795	1.6326	1.8594	1.125	5.8095
Buildings	0.5004	0	0.0171	9.0945	0.0414	566.3178	575.9712
Total	4500.0486	891.9414	2.331	1044.7479	3.2787	749.1285	

4.2 Changes in Carbon Reserves

Analysis indicated that the spatial distribution of carbon reserves in Nanchang city changes little from 2001 to 2021, and the carbon density in different regions has obvious spatial differences, and its range is 0-13.14t/hm^2. The main manifestations are: in 2001, 2011, and 2021, the carbon reserves in the northwest and the southeast were the highest, and the central ones were the lowest, forming a pattern of "high and low weeks" (Figure 4). In northwest and southeast regions, late development, good forest vegetation, and strong carbon fixation capacity; the central area of building land is increasing, dense population, high urbanization level, large water area, cropland area, and large carbon emissions, resulting in low carbon reserves.



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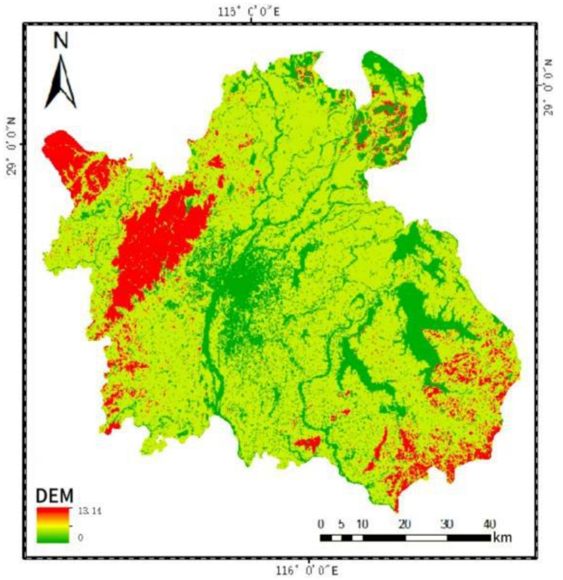
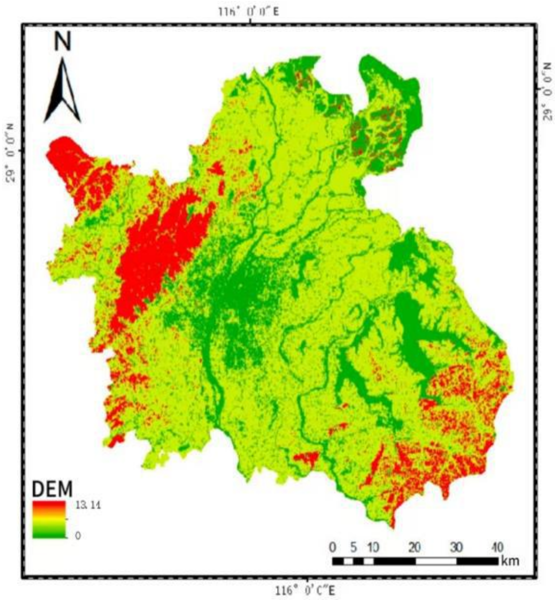
(a) Distribution of carbon reserves in 2001



(b) Distribution of carbon reserves in 2011



(c) Distribution of carbon reserves in 2021

Fig.4: Distribution diagram of carbon reserves

Through calculation, the total carbon reserves of Nanchang in 2001, 2011, and 2021 are 4.12107 t, 4.06107 t, and 4.01107 t, respectively. Consequently, in the two stages of 2001-2011 and 2011-2021, the carbon reserves of Nanchang city decreased continuously, but the decline in 2011-2021 was smaller than that in 2001-2011. Due to the good carbon fixation capacity of plant leaves and roots, the increase in forestland area after 2011 can increase the regional carbon reserves to a certain extent. With the continuous increase in urbanization rate, the sharp increase in building land area will also lead to the reduction of carbon reserves in terrestrial ecosystems. In recent years, the urban management department of Nanchang city has strengthened the management of landscaping construction (Chen and Wei, 2023). In 2020, the park area will be increased by 1 million square meters, and the green space and park site will be expanded through demolition and construction measures, forming a network system of "four horizontal, seven vertical, and six ring" urban greenways, which is of great significance to the improvement of regional carbon reserves.

In general, the distribution characteristics of urban carbon reserves are similar to those of urban vegetation, with a large vegetation area, high vegetation coverage, and higher regional carbon reserves.

V. CONCLUSION

This paper primary uses the land use type data of Nanchang city to analyze the land use change and applies the InVEST model to integrate the carbon density data to analyze the change of its carbon reserve.

From 2001 to 2021, the land use in Nanchang showed obvious spatial and temporal changes, and the overall change of cultivated land area showed a downward trend, especially in the central region, which is mainly the result of urban development and construction in the central region.

Under the influence of the change in land use type, the urban carbon reserves show a downward trend of continuous decrease. The high-value areas are mostly distributed in the northwest and southeast forest areas; the low-value areas are mostly distributed in the central urban construction areas; and other land types are between the two ranges. It shows that the decrease of cropland and the increase of building land are the main reasons for the decrease of carbon reserves.

To sum up, the government should take timely measures such as adjusting land use structure, strengthening land use management, and increasing ecological engineering construction; coordinate ecological environment protection; achieve scientific planning and reasonable development so as to coexist well with nature; promote carbon balance; and realize high-quality and low-carbon urban development.

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