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Land Use Change Monitoring and Carbon Storage Assessment in Qingyuan City Using the InVEST Model

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Abstract— *To analyze the spatial and temporal distribution characteristics of land use change and carbon stock in Qingyuan City from 1990 to 2020 and the relationship between them, to provide theoretical decision-making references for balancing economic development and ecological civilization construction and promoting rural revitalization. Based on remote sensing data, ArcGIS was used for land use change visualization, and the Carbon module of the InVEST model was used to estimate carbon stocks to explore the impact of Land Use and Cover Change (LUCC) on carbon stocks. The results show that from 1990 to 2020, the area of cultivated land, forest land, and grassland in Qingyuan City decreased, the area of construction land and water area increased, and the size of the unused land area remained unchanged. The land use type with the largest share of carbon stocks is forest land, and the smallest is unused land. The total carbon stock was 132,300,135 Mg (mega gram) in 1990 and 131,613,007 Mg in 2020, a decrease of 687,128 Mg in total carbon stock. Changes in the area of grasslands leading to changes in the area of carbon stocks are the most obvious, and the conversion of cultivated land, forested land, and grasslands to construction land is the main cause of the loss of carbon stocks..*

Keywords— Qingyuan City, Carbon Storage, Integrate Valuation of Ecosystem Services and Tradeoff (InVEST) Model, Land Use and Cover Change (LUCC).

I. INTRODUCTION

Climate change has become a severe environmental and social issue in this day and age with global impacts on nature and the economy [1]. Carbon stocks in terrestrial ecosystems are at the forefront of global carbon stock composition [2], and their impact on the global carbon cycle and climate change is enormous. Land Use and Cover Change (LUCC) is considered by many researchers as an important factor affecting the carbon cycle process in terrestrial ecosystems [3], and the study of land use change has a crucial effect on carbon storage, which is an important path to mitigate global warming.

In recent years, many scholars at home and abroad have conducted a large number of studies on the impact of LUCC on carbon stocks in terrestrial ecosystems. For example, Li et al [4] used the InVEST model to estimate the carbon stock in Daqing City from 2010 to 2020 and explored the impact of land cover change on it, and found that the conversion of grassland and wetland to cultivated land is the key reason for the loss of carbon stock and that the main contributor to the carbon stock of the ecological conservation scenario is wetland; Wu et al [5] explored the carbon stock changes in terrestrial ecosystems of Guangdong Province and the impact of urban expansion on carbon stocks from 1980 to 2010 based on the InVEST model, and found that the reduction of carbon stocks due to urban expansion in the Pearl River Delta (PRD) is over 80% of the total amount in the province; Zhang et al [6] analyzed the changes in ecosystem services and its spatial distribution characteristics in Hangzhou from 2000 to 2010, and found that the ability of regional climate regulation changes accordingly when land cover changes. Most of the studies on the relationship between land use change and carbon stocks are based on the InVEST model, which was jointly developed by Stanford University, the World Wide Fund for Nature (WWF), and The Nature Conservancy (TNC). The quantitative assessment of ecosystem services is expressed in the form of a graph, which solves the problem of abstract expression in words.

Most of the previous researchers took economically developed cities or larger regions as the research target, while there were fewer studies on small and medium-sized cities, and even fewer of them took Qingyuan City as the research area in the study of the relationship between LUCC and carbon stock.

Given this, this paper, based on summarizing the research results of previous researchers, takes Qingyuan City as the study area, based on the land use cover data from 1990 to 2020, and adopts the InVEST model to analyze the spatiotemporal distribution of the carbon stock from 1990 to 2020, and the influence of the land use changes on it. That is to provide decision-making reference for the ecological civilization construction, urbanization process, and comprehensive rural revitalization in Qingyuan City.

II. STUDY AREA AND DATA SOURCES

2.1 Study Area

Qingyuan City (located between latitude 23°26′56″-25°11′40″N and longitude 111°55′17″-113°55′34″E) is situated in the north-central part of Guangdong Province (Figure 1), in the middle and lower reaches of the Beijiang River, south of the southeastern hills, and on the combined belt of the southern side of the Nanling Mountain Range and the Pearl River Delta. It is known as the “Back Garden of Guangdong." By the tip of 2021, the total land area was about 19,000 square kilometers. At the end of 2023, the household population was about 4,533,500 and the resident population was about 3,986,700.

In terms of topography and geomorphology, its terrain displays a high northwest and low southeast, with the eastern part of Lianzhou and the northeastern part of Yangshan being one of the most precipitous mountainous areas in Guangdong Province. Comparatively speaking, the southeastern areas of Qingxin, Qingcheng, and Yingde are located in the valley area of the Beijiang River; therefore, the terrain is relatively low and flat, with an elevation of basically less than 20 meters.

In respect of climate, it belongs to the Subtropical monsoon climate zone, with distinct seasons, sufficient light, and abundant rainfall. The average annual temperature is 20.7 °C, and the average annual precipitation is 1,909 mm. In the development of the economy, efforts to build “ten billion agricultural industries"—Qingyuan chicken, Yingde black tea, Lianzhou cabbage, hemp bamboo shoots, and silk seedling rice—five special agricultural products—to promote the high-quality development of agriculture in Qingyuan City with a unique “Qingyuan way” to help revitalize the countryside.

2.2 Data Sources

The data used in this paper consists of five items, each of which is stated below:

(1) Elevation data (DEM): derived from a geospatial data cloud (GDC) (https://www.gscloud.cn/), with operations such as merge and extraction by mask in ArcGIS;

(2) Meteorological data: average annual precipitation and average annual temperature from the Qingyuan Municipal People's Government Portal (http://www.gdqy.gov.cn/), and the Guangdong Provincial Intelligence Network (https://dfz.gd.gov.cn/), used to calculate carbon pool data;

(3) LUCC data: 1990-2020 remote sensing monitoring raster data of the current land use situation in China, with a spatial resolution of 1km, data from the Resource and Environment Science Data Center of the Chinese Academy of Sciences (http://www.resdc.cn);

(4) Carbon pool data: Referring to the study of carbon

density in Guangdong Province by Lin Tong and Yang Muzhuang, etc. [7], the database of carbon density of land use types in Qingyuan City was finally obtained with corrections;

(5) Administrative division data: administrative boundaries of Guangdong Province, Qingyuan City, districts, and counties, data from the website of the National Basic Geographic Information System (http://ngcc.sbsm.gov.cn/).

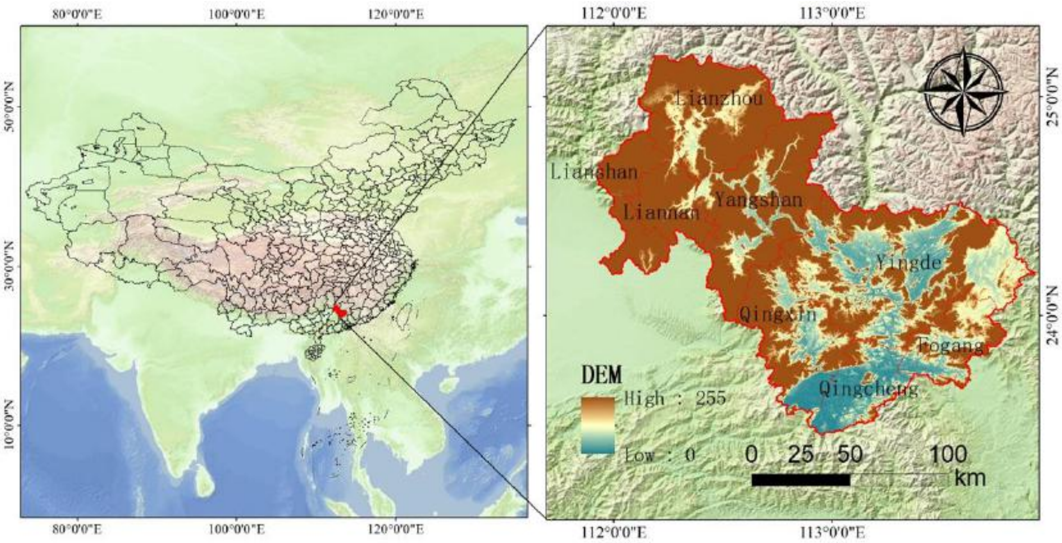

Fig.1 Elevation and Geographic Location of Qingyuan City

III. RESEARCH METHOD

3.1 Research Process

The process of this study is as follows: first, the data are collected and organized, which are DEM remote sensing data, administrative boundaries, LUCC from 1990 to 2020, meteorological data, and carbon density of Guangdong Province in Qingyuan City. Inputting the former three data into ArcGIS for extracting and series operation by mask, we can get the distribution of land use types in Qingyuan City at each time point. Then the LUCC data are reclassified to get the first level of land use classification; the carbon density of Guangdong Province is combined with the average annual temperature and precipitation using the carbon density correction formula to calculate, thus we can get the carbon density data of Qingyuan City; the two data are organized into the required format and inputted into the InVEST model, and then the carbon stock estimation value is achieved. Finally, the results obtained were mapped by using ArcGIS and Origin to visualize the abstract textual data for easier analysis (Figure 2).

3.2.1 Carbon Storage Calculation based on the InVEST Model

In this paper, based on the land cover type first-level classification maps and the carbon density of four carbon pools (above-ground biomass, underground biomass, soil, and dead organic matter), we applied the Carbon module of the InVEST model to estimate carbon stocks at a time point of every ten years, starting from 1990. The detailed carbon stock calculation formula is:

$$C_T=C_a+C_b+C_s+C_d \quad (1)$$

In the formula, C_T is the total carbon stock, C_a is the above-ground carbon stock, C_b is the below-ground carbon stock, C_s is the soil carbon stock, and C_d is the dead organic matter carbon stock.

Carbon density data corresponding to different land classes in Guangdong Province were obtained through the study of Lin Tong et al. [7]. The dead organic matter carbon stock was not considered in this study due to the difficulty of obtaining it and its relatively small share in the carbon pool [8]. The major calculations are aboveground vegetation, belowground vegetation, and soil carbon density values for land use types under various primary classifications.

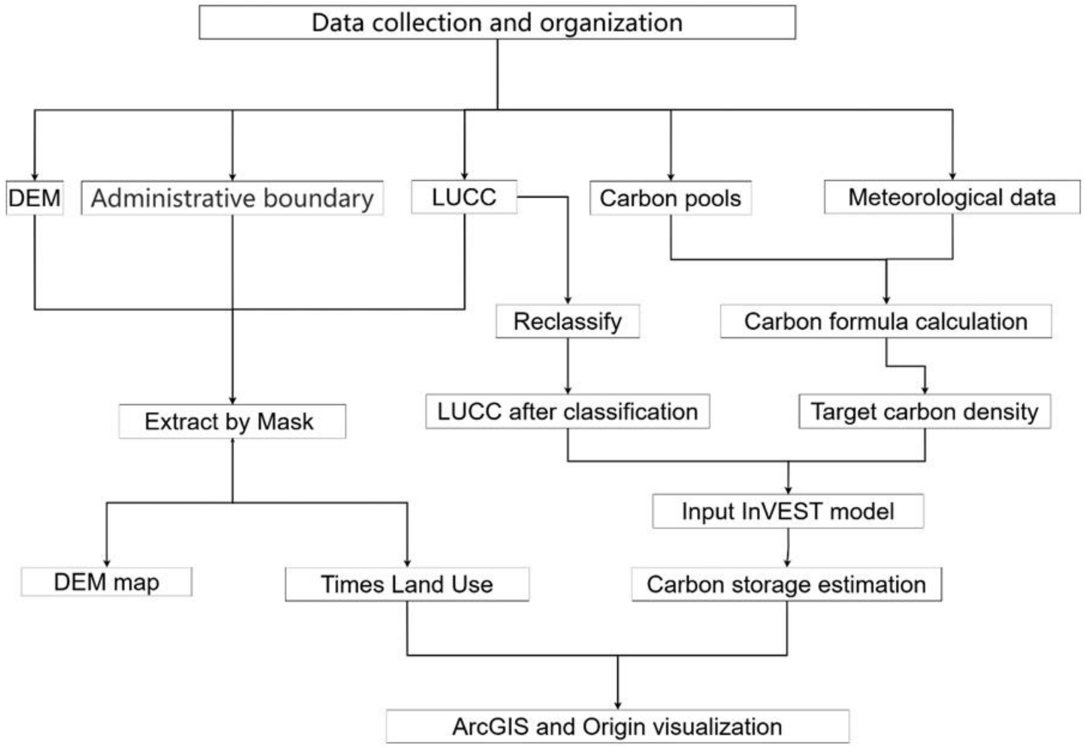

Fig.2 Flow Chart of the Study

3.2.2 Carbon Density Correction

Referring to Guangdong Province Situation Network (https://dfz.gd.gov.cn/) "Guangdong Yearbook 2019" and Qingyuan Municipal People's Government Portal (http://www.gdqy.gov.cn/) "2023 Qingyuan Climate Bulletin," we get the average temperatures of Guangdong Province and Qingyuan City are 21.8°C and 20.7°C, and the average rainfall is 1789.3mm and 1909mm. Based on the principle of a high degree of generalization and more similar climatic conditions, the carbon density correction formula was selected to correct the carbon density of Guangdong Province [7]. The equations for the relationship between annual precipitation and soil carbon density (equation 2, 3) were drawn from Alam's study [9], while the relationship between mean annual temperature and biocarbon density was drawn from Chen Guangshui et al.'s study [10] (Eq. 4). The exact carbon density correction formula is as follows:

$$C_{SP}=3.3968\times MAP+3996.1 \quad (2)$$

$$C_{BP}=6.798\times e^{0.0054\times MAP} \quad (3)$$

$$C_{BT}=28\times MAT \quad (4)$$

Where: C_{SP} is the soil carbon density (kg/m^2) based on annual precipitation, C_{BP} and C_{BT} are the biomass carbon densities (kg/m^2) according to the annual average precipitation and annual average temperature, MAP is the annual average precipitation (mm), and MAT is the annual average temperature (°C).

Take the average annual temperature and average annual precipitation values of Guangdong Province and Qingyuan City into the above formula, and the ratio of the two is the carbon density correction factor of Qingyuan City.

$$K_{BP}=\frac{C'_{BP}}{C''_{BP}};K_{BT}=\frac{C'_{BT}}{C''_{BT}}$$

$$K_B=K_{BP}\times K_{BT}=\frac{C'_{BP}}{C''_{BT}}\times\frac{C'_{BT}}{C''_{BT}} \quad (5)$$

$$K_S=\frac{C'_{SP}}{C''_{SP}} \quad (6)$$

In the equation: K_{BP}, K_{BT} are the corrector coefficients of precipitation factor and temperature factor for biomass carbon density; C′ and C″ are the carbon density data of Qingyuan City and Guangdong Province, K_B, K_S are the aboveground and belowground biomass carbon density correction coefficients and the soil carbon density correction coefficient, respectively. Multiply the correction coefficient with the carbon density value of

Guangdong Province to get the carbon density data of Qingyuan City, and finally get the carbon density data of each category in Table 1. This was used to calculate the carbon stock in the study area for different periods and different land use types [11].

Table 1 Corrected Carbon Density of Land Cover Types (Mg/hm²)

Land cover type	Aboveground biomass	Underground biomass	Soil
Cultivated land	29.12	5.82	11.28
Forest	35.6	10.68	20.06
Grass	29.71	154.5	10.39
Waters	0.21	1.01	1.26
Construction	20.87	4.18	18.7
Unused	25.76	5.15	5.55

IV. RESULTS AND ANALYSIS

4.1 Analysis of Land Use Change

The ArcMap raster calculator was used to obtain the land use transfer matrix for each type from 1990 to 2020 (Table 2) and combined with Origin mapping software to produce a Sankey map of the land cover transfer from 1990 to 2020 (Figure 3) to visually analyze the land use cover changes.

The results show an increase in construction land and water area, with the largest increase being in construction land, which increased by 258km², and water area, which increased by 35km². Except for the size of unused land, which did not change, all the other land use types are in a state of decrease, of which the first place is cultivated land, with a decrease of 213km², and the total area of each type of decrease is 293km², with cultivated land accounting for 72.70% of the total decrease. The smallest decrease was in grassland, which decreased by only 10 km², accounting for 3.41%. In the middle of the list of decreases is forest land, with a decrease of 70km², accounting for 23.89%. The largest source of increase in construction land is cultivated land with 241km² converted, followed by forest land with 104km² converted, which is the main source of increase in the area of construction land. The least conversion to construction land was unused land, with only 1km² converted over thirty years. The most conversions to waters were also cultivated land with a total of 110km². Cultivated land converted the most into forest land at 799km², while forest land converted the most into cultivated land, totaling 788km², with conversions between cultivated land and forest land essentially equal. Grassland was mostly converted out to forest land, totaling 296km². Waters and construction land were the most converted to cultivated land, totaling 73km² and 97km², respectively.

Table 2 Land Use Transfer Matrix of Qingyuan City, 1990-2020 (km²)

Year		2020					
Land use type		Cultivated land	Forest	Grass	Waters	Construction	Unused
1990	Cultivated land	2891	799	114	110	241	1
	Forest	788	11634	286	44	104	0
	Grass	94	296	903	2	34	0
	Waters	73	39	9	200	15	0
	Construction	97	18	7	15	168	0
	Unused	0	0	0	0	1	0

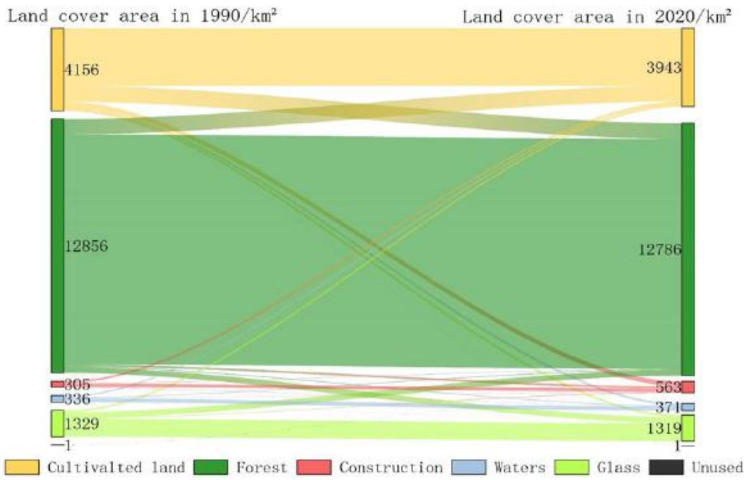

Fig.3 Sankey map of land cover transfer in Qingyuan City, 1990-2020

From the viewpoint of spatial layout (Figure 4), among the four points in time, construction land is clustered in the urban area of Qingyuan City, that is, Qingcheng District, while the rest is basically scattered in the economic centers of counties and county-level cities, without any obvious clustered distribution of construction land even in Qingxin District. During the period, the expansion of construction land in Qingcheng District and Yingde City was obvious, and the construction land in the remaining areas was not significant but also expanded, with construction land expanding area mainly through encroachment on cultivated land. The phenomenon of conversion of grassland to forest land in the eastern part of Yangshan County is evident in the second and third time points, but it recovers in the last time point, and the rest of the land use types do not change significantly.

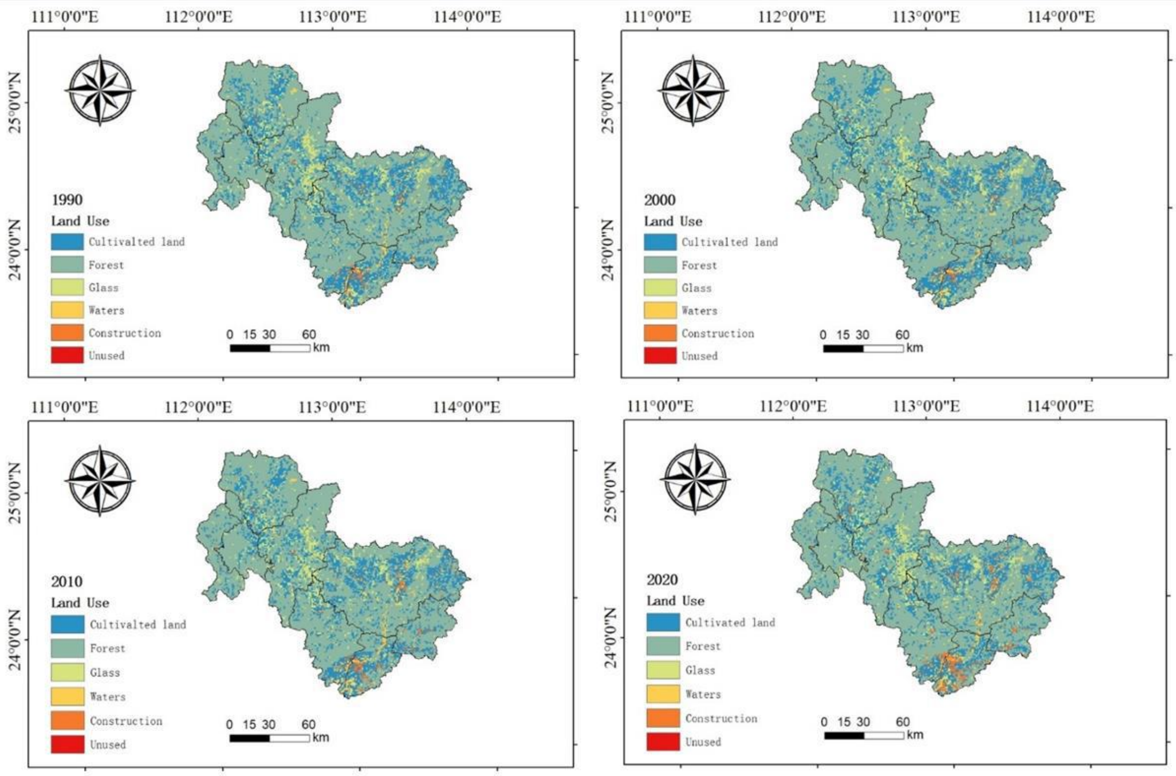

Fig.4 Distribution of land use types in Qingyuan City, 1990-2020

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4.2 Distribution and Spatiotemporal Variation of Carbon Storage

By inputting the distribution of land use types and the corrected carbon density data into the InVEST model, the spatial distribution map of carbon stocks at each time point can be obtained (Figure 5). The spatial distribution of carbon stock in Qingyuan City has not changed much in the past three decades, and the low carbon stock area is mainly located in the junction of Qingcheng District and Qingxin District, and the northern part of Yingde and Lianzhou; the high carbon stock area shows a clustered distribution in the eastern part of Yangshan County and the junction of Yangshan County, Qingxin District and Yingde City. Liannan Yao Autonomous County, Lianshan Zhuang Yao Autonomous County, and Fogang County are basically medium. The overall situation is characterized by "high in the middle, low in the south, and medium in the northwest".

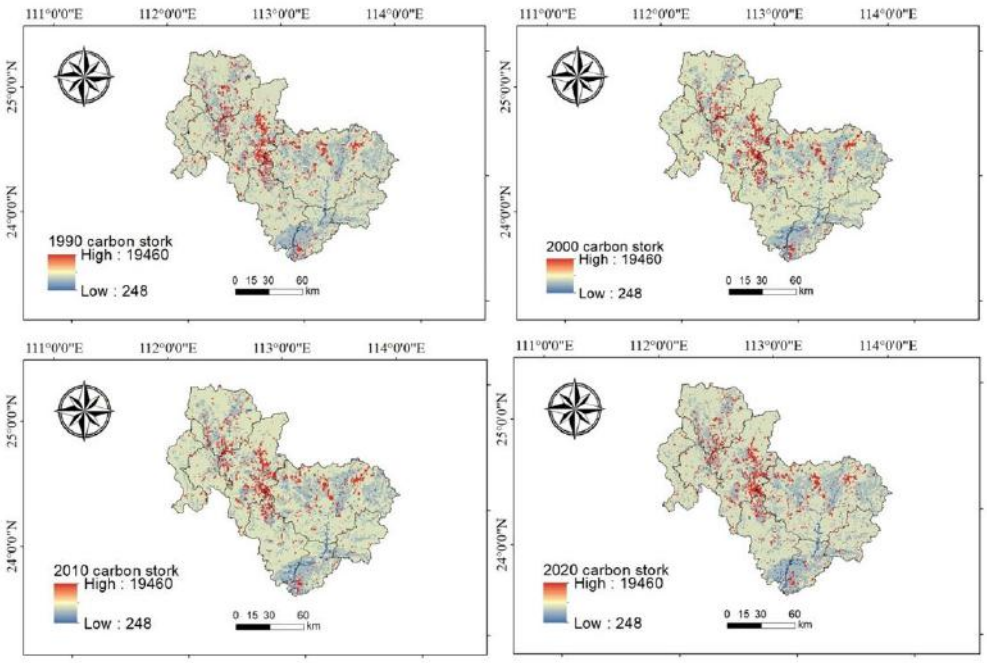

Fig.5 Spatial Distribution of Carbon Stocks in Qingyuan City, 1990~2020

From the analysis of the main land use types (Table 3), the carbon stocks at each time point were, from largest to smallest: forest land > grassland> cultivated land > construction land > waters > unused land, respectively. The land use type with the largest carbon stock in 1990 was forest land, which accounted for 64.77% of the city's total, totaling 85,691,378 Mg. The reason for this was the high carbon density of forest land itself and the fact that forest land was the most extensive among the various land types within Qingyuan. By 2020, forest land was still the largest land use type in terms of carbon stock, accounting for 64.65%, followed by grassland (19.55%) and cultivated land (13.85%).

Analyzing the carbon stock changes of each land use type in the past 30 years (Figure 6), the carbon stock of forest land in Qingyuan City first had a slight decline, then rose in the middle, and finally declined again, with a total reduction of 59.71 × 10^4 Mg; the carbon stock of cultivated land first rose, then declined, with a reduction of 99.37 × 10^4 Mg; and the carbon stock of grassland first declined, then rose, but up to 2020, it still declined by 23.35 × 10^4 Mg. On the other hand, the carbon stock of construction land decreased slightly between 1990 to 2000 but showed a spike after 2000 with the rapid expansion of the area, and finally, the carbon stock of this land category increased by a total of 112.87 × 10^4 Mg. Carbon stocks in waters show slow growth, and unused land carbon stocks show growth due to the change in area and finally also rebound with the area. The area of the most carbon-intensive land use types has decreased significantly over the last 30 years, resulting in a decrease in total regional carbon stocks.

Table 3 Land Use Carbon Stock in Qingyuan City, 1990-2020 ($\times 10^4$ Mg)

Land use type	1990 年	2000 年	2010 年	2020 年
Cultivated land	1922.75 （14.53）	1924.14 （14.59）	1871.45 （14.26）	1823.38 （13.85）
Forest	8569.14 （64.77）	8563.17 （64.93）	8586.39 （65.43）	8509.43 （64.65）
Grass	2595.96 （19.62）	2560.94 （19.42）	2483.10 （18.92）	2572.61 （19.55）
Waters	8.36 （0.06）	8.48 （0.06）	9.13 （0.07）	9.20 （0.07）
Construction	133.44 （1.01）	130.38 （0.99）	171.06 （1.30）	246.31 （1.87）
Unused	0.36 （0.00）	1.09 （0.01）	1.09 （0.01）	0.36 （0.00）
Total	13230.01 （100.00）	13188.19 （100.00）	13122.21 （100.00）	13161.30 （100.00）

Note: Percentage in ( ), %.

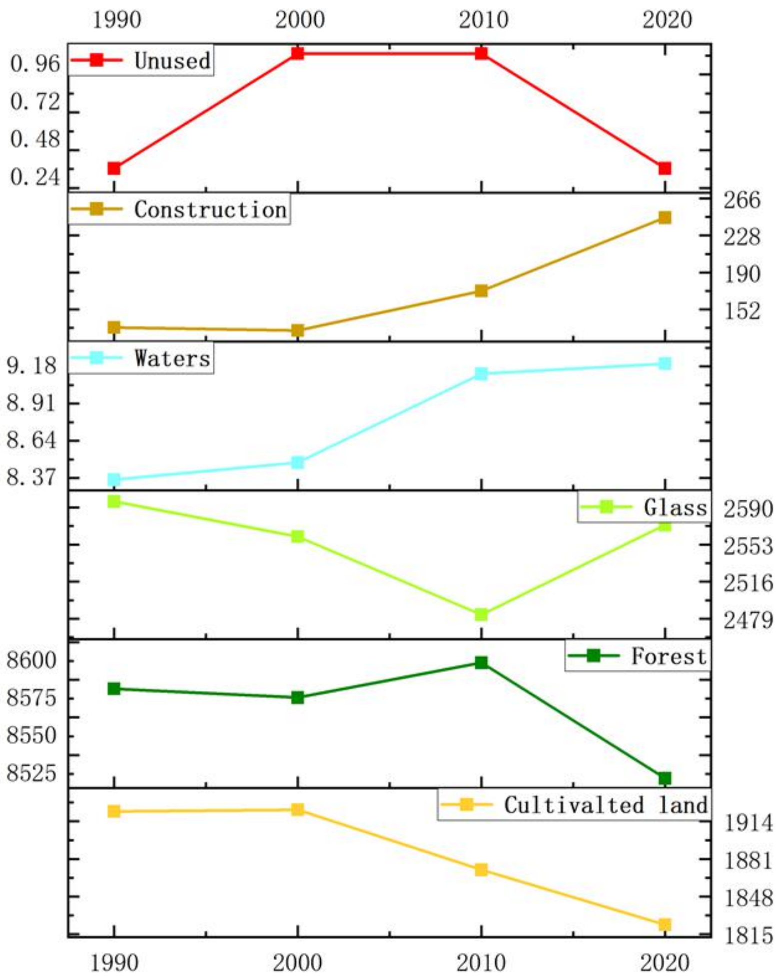

Fig.6 Temporal Change of Carbon Stock by Category in Qingyuan City, 1990-2020

4.3 The Impact of Land Cover Change on Carbon Storage

Based on the comprehensive analysis of land cover and carbon stock change characteristics at each time point in the study area, the area of cultivated land decreased the most during the 30 years (213 km^2), thus resulting in the largest reduction of carbon stock in cultivated land, with a total reduction of 99.37 × 104 Mg. The area of construction land increased the most (258 km^2), so the increase in carbon stock in it was also the most, totaling 112.88 × 104 Mg. The area of construction land increased the most (258 km^2), so the increase in carbon stock in it was also the most, totaling 112.88 × 104 Mg; however, the increase in carbon stock brought about by the increase in construction land was much smaller than the decrease in carbon stock from the degradation of other land use types. The amount of area reduction in grassland is much lower than cultivated land, but compared to other land cover types, grassland area reduction leads to the most significant change in carbon stock, with a loss of carbon stock of about 2.36 × 104 Mg per 1 km² of grassland reduction.

On the contrary, the change in carbon stocks due to an increase in water area is the weakest, with an increase of only 0.024 × 104 Mg per 1 km² of additional waters. Thus, the dominant factors of carbon stock changes during the studied thirty years were the changes in grassland, forest land, and cultivated land. Taking 1990 as the starting point and 2020 as the endpoint, the carbon stock in Qingyuan City decreased by a total of 68.71 × 104 Mg during the thirty years

V. CONCLUSIONS

Based on the InVEST model, monitoring the changes in land use types and estimating the carbon stock in Qingyuan City in the last thirty years, the following conclusions were drawn:

(1) Changes in land-use types: the areas of cultivated land, forest land, and grassland have all decreased, with the area of cultivated land decreasing by a maximum of 213km². The area of construction land and waters increased, with the largest increase in the area of construction land being 258km²; the area of unused land fluctuated slightly during the study period, but the final area remained the same as at the beginning. By 2020, the percentage of the area of each land use type was: cultivated land (20.77%), forest land (67.36%), grassland (6.95%), waters (1.95%), construction land (2.97%), and unused land (0.01%). Construction land is mainly concentrated in Qingcheng District and southeastern Qingxin District, and the expansion of construction land in Yingde over the past thirty years has been more obvious; cultivated land is mainly clustered in Lianzhou, Yangshan, and Yingde. Grassland is distributed continuously in the eastern part of Yangshan and part of Yingde.

(2) Change in carbon stock: In the past thirty years, the carbon stock in Qingyuan City has decreased by 68.71 × 10^4 Mg, mainly since a large amount of cultivated land, forest land, and grassland have been developed and constructed as construction land and waters. The distribution of carbon stocks is similar to the type of land use, with areas where cultivated land, forest land, and grassland are located having correspondingly higher carbon stocks. Yangshan County, which has the widest distribution of grassland, has the highest corresponding carbon stock, while Qingcheng District, which has the highest degree of urbanization and development, has the largest area of construction land distribution with the lowest corresponding carbon stock in Qingcheng District. Qingyuan City as a whole is characterized by “high in the middle, low in the south and medium in the northwest”.

(3) Carbon stock is one of the important indicators for measuring the function of ecosystem services, which is inextricably linked to the survival and development of human beings and at the same time has an important relationship with the sustainable development of the region. From Figure 5, it can be seen that the carbon stock in the Qingcheng urban area of Qingyuan City has decreased most significantly over the past thirty years, and the rapid economic development may hurt the carbon stock by changing the type of land use, increasing the carbon emission and affecting the ecosystem function. The coordinated development of the economy and ecological protection is a requirement set out in national development plans and an important task for sustainable development.

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