International Journal of Rural Development, Environment and Health Research
[Vol-7, Issue-4, Jul-Aug, 2023]
Issue DOI: https://dx.doi.org/10.22161/ijreh.7.4
Article DOI: https://dx.doi.org/10.22161/ijreh.7.4.2
ISSN: 2456-8678 ©2023 IJREH Journal

Impact of Land Use/Cover Change (LUCC) on Carbon Storage in Zhaoqing by using the InVEST Model

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Received: 01 Jun 2023; Received in revised form: 02 Jul 2023; Accepted: 09 Jul 2023; Available online: 19 Jul 2023

Abstract

Exploring the impact of Land Use/Cover Change (LUCC) on ecosystem carbon storage is of great significance for promoting low-carbon development. Based on the land cover data from 2000 to 2020 interpreted by remote sensing, this study uses the InVEST model to analyze the relationship between the spatial and temporal changes of carbon storage in the ecosystem of Zhaoqing City and land cover. The results show that: 1) In the past 20 years, the area of land cover types in Zhaoqing City has not changed much; the area of cultivated land, forest land, and grassland has decreased; and the area of water area, construction land, and unused land has increased. 2) The carbon storage volume in 2000, 2010, and 2020 were 296.74×10^{6}t, 297.00×10^{6}t, and 290.50×10^{6}t, respectively. Carbon storage increased at first and then decreased, showing an overall downward trend. 3) High carbon reserves are distributed in the central and northern mountainous areas of Zhaoqing City; medium carbon reserves are distributed in the western basin of Huaiji County; and low carbon reserves are distributed in the southern area of Zhaoqing. 4) From 2000 to 2010, the conversion between forest and grassland resulted in relatively stable carbon storage and an increase of 201,200 tons. The conversion of forest land and cultivated land into construction land and water has reduced carbon storage by 6.5745 million tons.

Keywords— *InVEST Model; Land Use/Cover Change (LUCC); Support Vector Machine (SVM); Carbon Storage; Carbon Density.*

I. INTRODUCTION

The issue of global climate change is becoming increasingly severe, and "carbon reduction" has become a global consensus and a research focus for domestic and foreign scientists. In 2020, the Chinese government announced at the 75th United Nations General Assembly that it aims to peak carbon emissions by 2030 and achieve carbon neutrality by 2060. It shows that it is urgent to attach importance to the carbon issue. Among them, the Terrestrial ecosystem, as one of the most important ecosystems on the surface, plays a critical role in regulating and mitigating the greenhouse effect. Its carbon storage refers to the total storage of aboveground and underground biomass organic carbon from plants, soil organic carbon, and litter organic carbon in the ecosystem. Different land cover types have different carbon fixation capacities, which directly affect the carbon storage of terrestrial ecosystems. Therefore, Land Use/Cover Change (LUCC) can alter carbon storage [2] [3]. Studying the factors that affect the carbon storage of ecosystems can provide important references for formulating future regional ecological protection policies.

LUCC are mainly due to human activity, thereby altering ecosystem carbon reserves. Traditional carbon storage estimation methods such as the storage method, biomass method, and box method are simple and clear in estimating carbon storage [4], but their efficiency is low, time-consuming, and labor-intensive, making them difficult to apply in large-scale research. In addition, these methods can only provide static carbon storage data and cannot timely reflect the dynamic changes in ecosystem carbon storage. Thus, it is necessary to combine remote sensing (RS) technology and geographic information systems (GIS) to construct a spatiotemporal integration, efficient, and fast carbon storage estimation method that can more accurately estimate the carbon storage of ecosystems, reveal their dynamic changes, and provide comprehensive support for environmental science and ecological protection work [5].

Recently, carbon storage estimation methods using model simulation have gained widespread attention. One of them, the InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) model, has become a commonly used method because it has the characteristics of low data demand and fast operation speed [6]. It can display the spatial distribution and dynamic changes of ecosystem carbon storage, reflect the relationship between LUCC and carbon storage, and achieve dynamic quantification of ecological service function value. Compared to previous single and static service value evaluation methods, this model can more comprehensively and accurately evaluate the ecological status of different countries and regions and is widely used in environmental science and ecological protection work.

Scholars in China have conducted a lot of research on the impact of LUCC on the carbon storage of Terrestrial ecosystems by using the InVEST method, which has become a mature methodology. For instance, Lv (2018) used the InVEST model to calculate the changes in carbon storage caused by different LUCC scenarios [7]. Rong et al. (2016) used the InVEST model to analyze the carbon storage function of LUCC in the Taihu basin [8]. Liu et al. (2021) used the InVEST model's carbon storage module and the CA-Markov model to explore and predict the temporal and spatial change characteristics of carbon storage in the ecosystem of the Shule River basin, as well as the relationship with land cover mode [9]. Based on this, this study is trying to use the InVEST model method for estimating LUCC and carbon storage.

Zhaoqing is a "forest city" with the largest forest area and the highest forest cover in the Guangdong-Hong Kong-Macao Greater Bay Area [10], and has important ecological resources such as high forest cover and high carbon reserves. As the ecological support of Guangdong Province, it plays a crucial role in promoting sustainable development and ecological protection. Therefore, this paper focuses on Zhaoqing City as the research area based on the data of land cover types in 2000, 2010, and 2020, obtains carbon density data by modifying the national carbon density, and uses the InVEST model to analyze the impact of land cover change on carbon storage in this city. It is trying to provide a scientific basis and theoretical support for its ecological civilization's construction and low-carbon development.

II. STUDY AREA AND DATA SOURCES

2.1 Study Area

Zhaoqing is one of the major cities in the Greater Bay Area (GBA), Guangdong Province, located at 22° 47′~24°24′N and 111°21 ′~112°52′E. The total administrative area of the city is 1.4897 million hectares, with Duanzhou District, Dinghu District, and Gaoyao District, and its jurisdiction is Guangning County, Deqing County, Fengkai County, Huaiji County, and Sihui (Figure 1). In 2022, the permanent population was 4.1284 million, with an urban population of 2.1525 million, accounting for 52.14% of the urban population.

The climate is the Tropical monsoon of South Asia, with an annual average temperature of 21.2 ℃ and rainfall of about 1650 mm. The landform is high in the northwest and low in the east and south. It inclines from northwest to southeast. It is composed of medium and low mountains and hills, with a few plains, forming landforms with an alternate distribution of mountains, basins, hills, alluvial plains, and other forms. The Xijiang River and the Beijiang River are two major water systems. The Xijiang River joins the Beijiang River in Sanshui District from west to east and flows into the Pearl River. The natural vegetation belongs to the subtropical evergreen monsoon rainforest and is one of the critical forest areas in Guangdong Province.

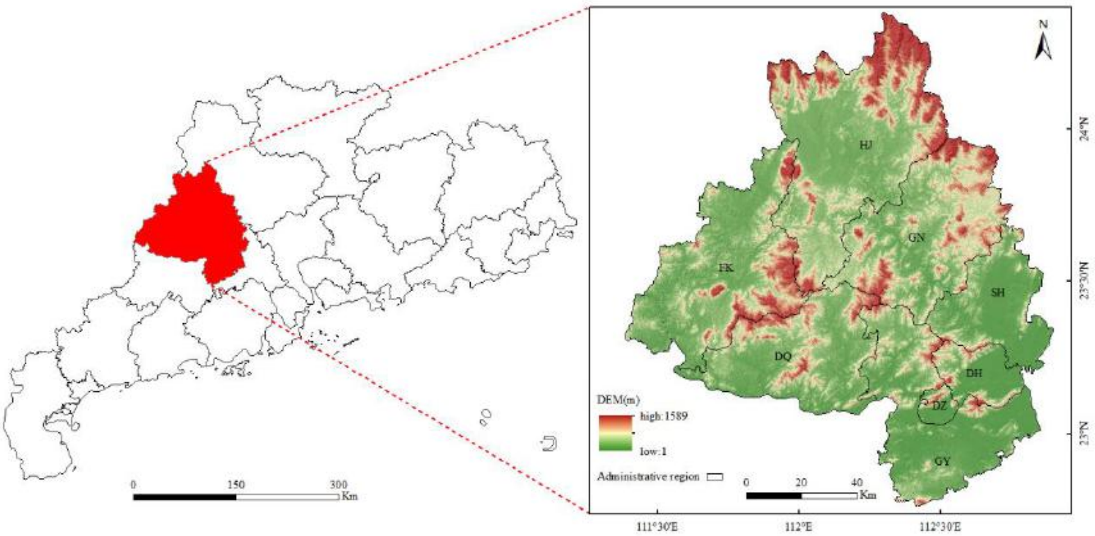

Fig.1 Topographic Overview of Study Area

Note: DZ refers to Duanzhou District, GY is Gaoyao District, DH is Dinghu District, SH is Sihui City, GN is Guangning County, HJ is Huaiji County, FK is Fengkai County, and DQ is Deqing County.

2.1 Data Sources

The data set for this study includes:

1. Administrative boundary data from the Resource and Environment Data Center of the Chinese Academy of Sciences (http://www.resdc.cn/data). After extraction, vector data for Zhaoqing City is obtained.
2. Remote sensing images, including Landsat 4-5 TM remote sensing imagery from 2000 and 2010, and Landsat 8 OLI_TIRS from 2020, with a spatial resolution of 30 m, come from the Chinese Academy of Sciences geospatial data cloud (http://www.gscloud.cn/search). After remote sensing interpretation, land cover data for the years 2000, 2010, and 2020 were obtained, which were divided into cultivated land, forest land, grassland,

water area, construction land, and unused land;

3. Carbon density data: By consulting literature and according to the climate conditions of Zhaoqing City, the carbon density is modified to obtain the carbon density of each land cover type.

III. METHODOLOGY

The technical process of this study (Figure 2) is divided into the following steps:

(1) Use ENVI software to preprocess and the Support Vector Machine (SVM) method to classify the three periods of remote sensing images of Zhaoqing City and get the land cover type map.

(2) According to previous studies and the climate characteristics of Zhaoqing City, the carbon density values were revised, and the carbon density data of various land cover types were obtained.

(3) The land cover type map and carbon density data are calculated using the InVEST model to obtain the distribution map and change map of carbon reserves.

(4) Analyze the impact of LUCC on carbon storage distribution using carbon storage distribution and change maps, as well as land cover type change maps.

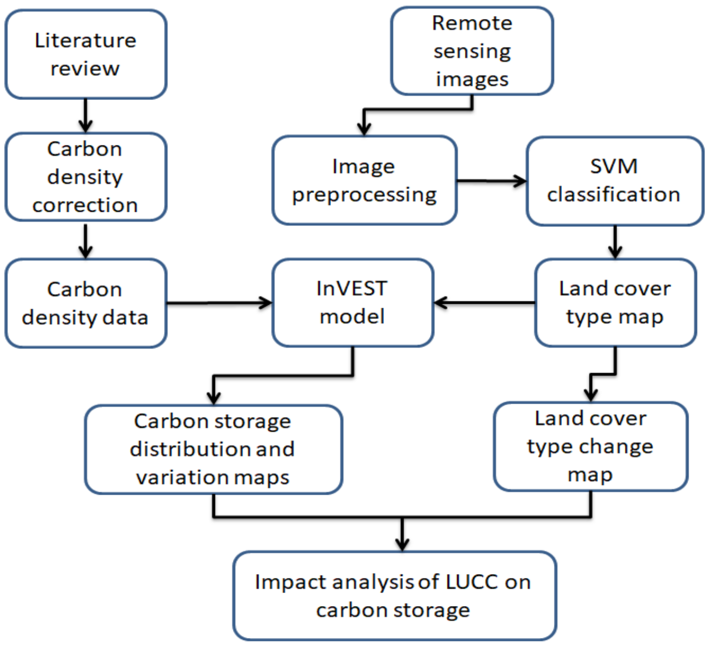

Fig.2 The technical process of this study

3.1 SVM Classification

Support Vector Machine (SVM) is a machine learning algorithm based on statistical learning theory developed by Vapnik (1995) team [11]. It is a machine learning model for remote sensing classification and has significant effect on small training data sets. Its core idea is that for linearly separable data, the data can be separated by finding the optimal hyperplane, which can maximize the separation of samples to be divided and ensure the maximum separation distance. For nonlinear separable data, based on the linear separable idea, the data points will be projected into a higher dimensional space (using kernel function technology) to find the optimal hyperplane in the high-dimensional space, so as to maximize the statistical dispersion between samples. SVM can effectively solve problems such as small samples, nonlinearity, and high dimensionality, and has strong generalization ability [12].

According to the basic Formula of SVM, the optimal classification function can be obtained as follows (1):

$$f(x) = sgn[(\omega \cdot x) + b] = sgn\left[\sum_{i=1}^{n} a_i^* y_i K(x_i, x_j) + b^*\right] \ldots\ldots\ldots\ldots (1)$$

In above equation, a_i^* is Lagrange multiplier, y_i is the category, $K(x_i, x_j)$ is the kernel function type, and b^* is the classification threshold.

The type of kernel function and the selection of its related parameters can affect the classification accuracy of SVM [12]. There are four types of kernel functions commonly used in SVM, mainly linear kernel function (LKF), polynomial kernel function (PKF), radial basis function (RBF), and sigmoid kernel function (SKF) [13]. The above kernel functions are as follows (2), (3), (4), and (5):

$$\text{LKF: } K(x_i, x_j) = (x_i \cdot x_j) \ldots\ldots (2)$$

$$\text{PKF: } K(x_i, x_j) = (\gamma(x_i \cdot x_j) + r)d, \gamma > 0 \ldots (3)$$

$$\text{RBF: } K(x_i, x_j) = EXP\left[-\frac{\| x - x_i \|^2}{\gamma^2}\right], \gamma > 0 \ldots (4)$$

$$\text{SKF: } K(x_i, x_j) = tanh[\gamma(x_i \cdot x_j) + r], \gamma > 0 \ldots (5)$$

In equation (3), γ is the gamma coefficient, d is the polynomial coefficient, and r is the offset value in the RBF and SKF, respectively.

3.2 Carbon Density Correction

The accuracy of the InVEST model depends on the input parameters, and selecting an appropriate land cover type and carbon density data is crucial when estimating ecosystem carbon storage. The research shows that the difference in carbon density between land types in the same climate zone is relatively small [14]. Therefore, the vegetation carbon density in this study is based on literature [15-18], while soil carbon density data is based on literature [19-20]. The carbon density of land types will be affected by many factors, such as precipitation, temperature, biomass, environment, etc. In order to improve the accuracy of the carbon density data of land types in Zhaoqing City, this paper uses precipitation and temperature as the correction factors and corrects them through the formula. The correction formula [21-22] is as follows: (6) (7) (8):

$$C_{SP} = 3.3968MAP + 3996.1 \ldots (6)$$

$$C_{BP} = 6.7981e^{0.00541MAP} \ldots (7)$$

$$C_{BT} = 28MAT + 398 \ldots (8)$$

In the formula, C_{SP} represents the soil carbon density (t/hm²) obtained from annual precipitation, C_{BP} is the biomass carbon density (t/hm²) obtained from annual precipitation, C_{BT} is the biomass carbon density (t/hm²) obtained from annual temperature, MAP is the annual precipitation (mm), and MAT is the annual temperature (℃).

The average annual temperature and annual precipitation (9℃/21.2℃, 628mm/1650mm, respectively) data of the whole country and Zhaoqing are substituted into the above formula, and the ratio of the two is the correction coefficient. Combining the above formula, the carbon density correction coefficient formula [23-25] is obtained, as shown in (9) (10) (11) (12):

$$K_{BP} = \frac{C'_{BP}}{C''_{BP}} \ldots (9)$$

$$K_{BT} = \frac{C'_{BT}}{C''_{BT}} \ldots (10)$$

$$K_B = K_{BP} \times K_{BT} = \frac{C'_{BP}}{C''_{BP}} \times \frac{C'_{BT}}{C''_{BT}} \ldots (11)$$

$$K_S = \frac{C'_{SP}}{C''_{SP}} \ldots (12)$$

Where: K_{BP} is the precipitation factor correction coefficient of biomass carbon density, K_{BT} is the temperature factor correction coefficient of biomass carbon density, C' is the carbon density data of Zhaoqing City, C" is the national carbon density data, K_B is the biomass carbon density correction coefficient, K_S is the soil carbon density correction coefficient. The carbon density data of Zhaoqing City is obtained by multiplying the carbon density correction coefficient and the national carbon density value (Table 1).

Table 1 Carbon Density Data of Different Land Cover Types in Zhaoqing City

Land Cover Type	Carbon Density / （t/hm²）		
	Aboveground Carbon Density	Underground Carbon Density	Soil Carbon Density
Cultivated Land	1.42	20.09	69.16
Forest land	10.56	28.86	151.14
Grass Land	8.79	21.54	63.74
Water Area	0.7	0	0
Construction	0.6	0.23	1.8
Unused Land	0.3	0.28	0.53

3.3 InVEST Model

InVEST is a set of model systems used to assess ecosystem service functions and their economic values and support ecosystem management and decision-making. It covers three major modules on ecosystem service function assessment: freshwater ecosystem assessment, marine ecosystem assessment, and terrestrial ecosystem assessment [26], of which the module of terrestrial ecosystem assessment includes multiple submodules such as biodiversity, carbon storage, crop pollination, and wood production. The carbon storage module of the InVEST divides the carbon storage of ecosystems into four basic carbon pools: above-ground biocarbon, underground biocarbon, soil carbon, and dead organic carbon [27]. When calculating the carbon storage model, the carbon density of a land cover type is regarded as a constant. Over time and with environmental changes, the carbon sequestration of any grid that does not change in any land cover type will not change [28].

When calculating the carbon storage of Zhaoqing City, first calculate the average carbon density of each carbon pool for different land cover types. Then, multiply the area of each land cover type by its corresponding carbon density and add the various carbon reserves obtained to obtain the carbon reserves of the whole Zhaoqing City. The calculation of carbon storage mainly considers the carbon density values of land cover types, including above-ground and underground vegetation and soil. Although dead organic matter is also a critical carbon pool in ecosystems, due to its low content, it accounts for a relatively small proportion of the entire carbon pool and does not need to be calculated separately. Thus, no relevant discussion will be conducted in this article [29]. The calculation formula for carbon storage is shown in (13):

$$C_{total} = C_{above} + C_{below} + C_{soil} + C_{dead} \dots\dots\dots\dots\dots\dots..(13)$$

In the formula, C_{total} represents the overall carbon storage of the ecosystem (t). C_{above} is the above-ground carbon storage (t) of vegetation, which exists in all surviving plants above the soil. C_{below} is the carbon storage (t) of the underground part of vegetation, which exists in the living root systems of plants. C_{soil} is the soil carbon storage (t), which is the organic carbon present in organic and mineral soils. C_{dead} is the carbon storage of dead organic matter (t), which exists in the litter, fallen, or standing dead trees.

In combination with the carbon density and the data on land cover type, the calculation formula for carbon storage for each land cover type in Zhaoqing is as follows (14):

$$C_{total\_i} = \left(C_{above_i} + C_{below_i} + C_{soil_i} + C_{dead_i}\right) \times S_i \dots\dots\dots\dots\dots\dots\dots (1$$

In the formula: i represent a certain type of land cover. C_{total_i} is the overall carbon storage (t) of land cover type i. C_{above_i} is the carbon density (t/hm^2) of the above-ground vegetation of land cover type i. C_{below_i} is the carbon density (t/hm^2) of the underground part of vegetation under land cover type i. C_{soil_i} is the soil carbon density (t/hm^2) of land cover type i. C_{dead_i} is the dead organic matter carbon density (t/hm^2) of land cover type i. S_i is the area (hm^2) of a certain land cover type i.

IV. ANALYSIS AND RESULT

4.1 Analysis of LUCC

Using ENVI software, we preprocess the remote sensing images of Zhaoqing in 2000, 2010, and 2020 and supervise their classification by SVM. The classified images were completed. The overall classification accuracy and Kappa coefficient were 83.9% and 0.81, respectively. Finally, the distribution map of land cover types was obtained. The spatial distribution of land cover from 2000 to 2020 (Figure 3), is mainly composed of forest land, cultivated land, and grassland, which account for nearly 95% of the total area (Table 2).

The overall area of forest land accounts for 68.63% of the city's total area and is widely distributed in various regions. The reason for the high forest cover is the widespread distribution of 23 nature reserves in various regions. The cultivated land accounts for 14.18% of the total area of the city, mainly distributed in the northwest of Huaiji County, the northeast of Fengkai County, Sihui City, Dinghu District, and the southeast of Gaoyao District. Grassland distribution is not concentrated (8.77%), which is fragmented and distributed in various regions, relatively concentrated in the north of Huaiji County and Deqing County.

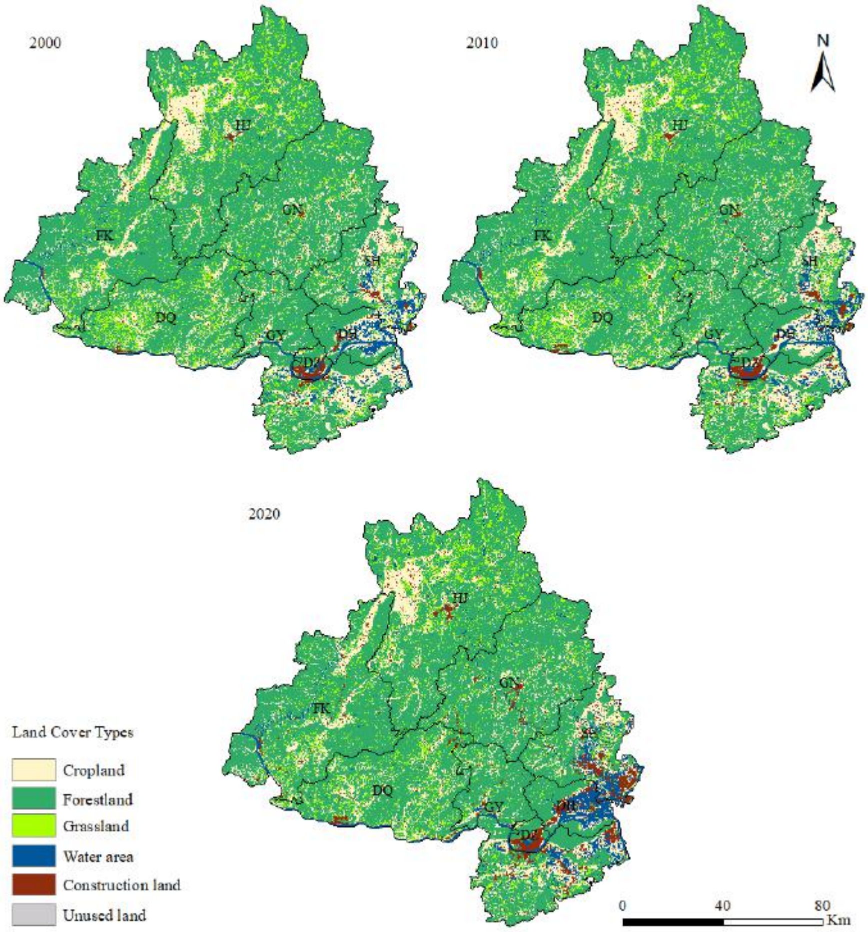

Fig.3 Spatial Distributions of Land Cover Types in Zhaoqing from 2000 to 2020

Table 2 Area and Proportion of Different Land Cover Types in Zhaoqing

Land Cover Type	2000 Year		2010 Year		2020 Year	
	Area /km²	Proportion /%	Area /km²	Proportion /%	Area /km²	Proportion /%
Cultivated Land	2460.71	16.52	2379.54	15.97	2112.02	14.18
Forest land	10272.14	68.95	10307.92	69.19	10224.55	68.63
Grass Land	1408.22	9.45	1428.27	9.59	1306.33	8.77
Water Area	522.76	3.51	514.28	3.45	674.87	4.53
Construction	230.48	1.55	266.52	1.79	575.48	3.86
Unused Land	3.14	0.02	0.92	0.01	4.20	0.03

In addition, the overall water area accounts for 4.53% of the city's total area, mainly the Xijiang and Suijiang rivers. The total area of construction land accounts for 3.86%, which is distributed in Duanzhou District, the middle of Dinghu District, and the southeast of Sihui City, especially Duanzhou District. In terms of the political, economic, and cultural center of Zhaoqing City, most of the area is occupied by construction land. The unused land area is small, accounting for less than 0.1%.

The area of LUCC in Zhaoqing City from 2000 to 2020 is forest land, cultivated land, and grassland. The area of water area, construction land, and unused land is small, accounting for only 8.42% of the total area. Over the past 20 years, there have been changes in various categories, with the largest change in the area being cultivated land, which has continuously decreased. By 2020, the cultivated land area had decreased by 348.69 km2, a 4.17% decrease. The construction land continues to increase, and by 2020, the construction land area has increased by 345 km2, with a growth rate of 149.69%. Both forest land and grassland increased first and then decreased, and overall they decreased. Compared with 2000, the grassland area decreased by 7.24% and the forest land area decreased by 0.46%. The water area and unused land all decreased first and then increased, with an overall increase. Compared to 2000, the water area increased by 29.10% and the unused land area increased by 33.76%. Overall, the area of cultivated land has decreased the most, while the area of construction land has increased the most.

According to the land cover stochastic matrix (Table 3) and land cover transfer map (Figure 4) of Zhaoqing from 2000 to 2020, the amount of grassland, cultivated land, construction land, and forest land transferred in the past 20 years is large, and the total amount of grassland transferred out is 692.43 km². Among them, forest land, construction land, and cultivated land transferred out accounted for 81.52%, 8.22%, and 7.62%, respectively. A total of 617.58 km² of cultivated land has been transferred. Among them, forest land, construction land, and water area transferred out account for 32.55%, 28.81%, and 30.08%, respectively. A total of 849.08 km² of forest land has been transferred. Among them, grassland, construction land, and cultivated land transferred out accounted for 61.87%, 11.04%, and 18.81%, respectively. The rapid increase in construction land, with a total of 374.68 km² of construction land transferred, means that 47.49% of it comes from cultivated land and 25.03% from forest land. The rapid increase in construction land area is due to the increasing demand for social and economic development, the rapid urbanization process, and the use of land by local governments as an important means of attracting investment, leading to the rapid expansion of urban and industrial land, which occupies a large amount of cultivated land.

Due to the government's implementation of the policy of "occupying one to supplement one" for cultivated land, strengthening the control of land use [30], the cultivated land occupied by construction land is supplemented by forest land. At the same time, people's demand for aquatic product consumption is also increasing, and the area of aquaculture has also increased, promoting the rapid development of the fishpond industry in Zhaoqing. The water area increased by 278.22 km², which converted from cultivated to water. The regional differences in land cover transfer in Zhaoqing are large. The increment of construction land is excessively concentrated in Duanzhou District, and the increase of water area is concentrated in Dinghu District and Sihui, which reflects the imbalance of regional development in Zhaoqing.

Table 3 Land Cover Stochastic Matrix of Zhaoqing from 2000 to 2020 (unit: km²)

2000 **Year**	2020 **Year**					
	Grass Land	Forest land	Construction	Forest land	Water Area	Unused Land
Grass Land	715.63	52.76	56.91	564.44	18.08	0.24
Cultivated Land	52.52	1842.71	177.94	201.05	185.76	0.31
Construction	2.31	17.41	200.80	5.56	4.31	0.02
Forest land	525.36	159.73	93.77	9421.85	67.39	2.83
Water Area	10.53	38.94	46.00	30.03	396.31	0.56
Unused Land	0.00	0.13	0.06	0.03	2.68	0.24

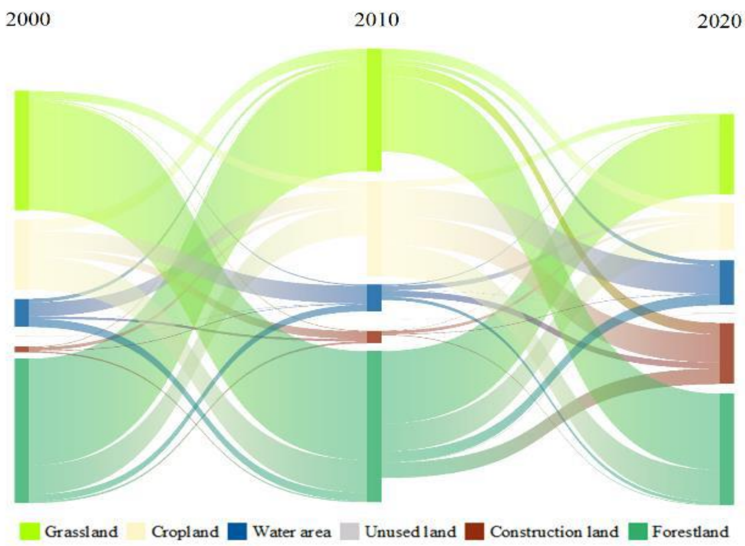

Fig.4 Land Cover Transfer Map of Zhaoqing City from 2000 to 2020

4.2 Analysis of Changes in Carbon Storage

This study, by referring to relevant literature and formula correction, obtained the carbon density data of land cover types in Zhaoqing. Combined with the current year's land cover data, which was imported into the carbon module of the InVEST model for operation, then we obtained the carbon reserve values for 2000, 2010, and 2020 (Figure 5 and Table 4). It is shown that forest land contributes over 80% of carbon storage, which is related to 69% of forest land cover. Secondly, cultivated and forest land account for a relatively large proportion of carbon storage, while water bodies, construction land, and unused land account for a very small proportion of carbon storage. The calculation data shows that the average carbon density in 2000, 2010, and 2020 was 19918.84 t/ km^2, 19936.23 t/ km^2, and 19500.24 t/ km^2.

From a time perspective, the carbon reserves in 2000, 2010, and 2020 were 296.74×10^6t、297.00×10^6t、290.50×10^6t, carbon storage first increased and then decreased, showing an overall downward trend. Total carbon storage increased by 2.59×10^5t from 2000 to 2010, compared to 2000, the growth rate is 0.09%. From 2010 to 2020, carbon storage decreased by 6.50×10^6t, a decrease of 2.19% compared to 2010. A reduction is 6.24×10^6t in total carbon storage from 2000 to 2020, with an average annual reduction of 3.12×10^5t.

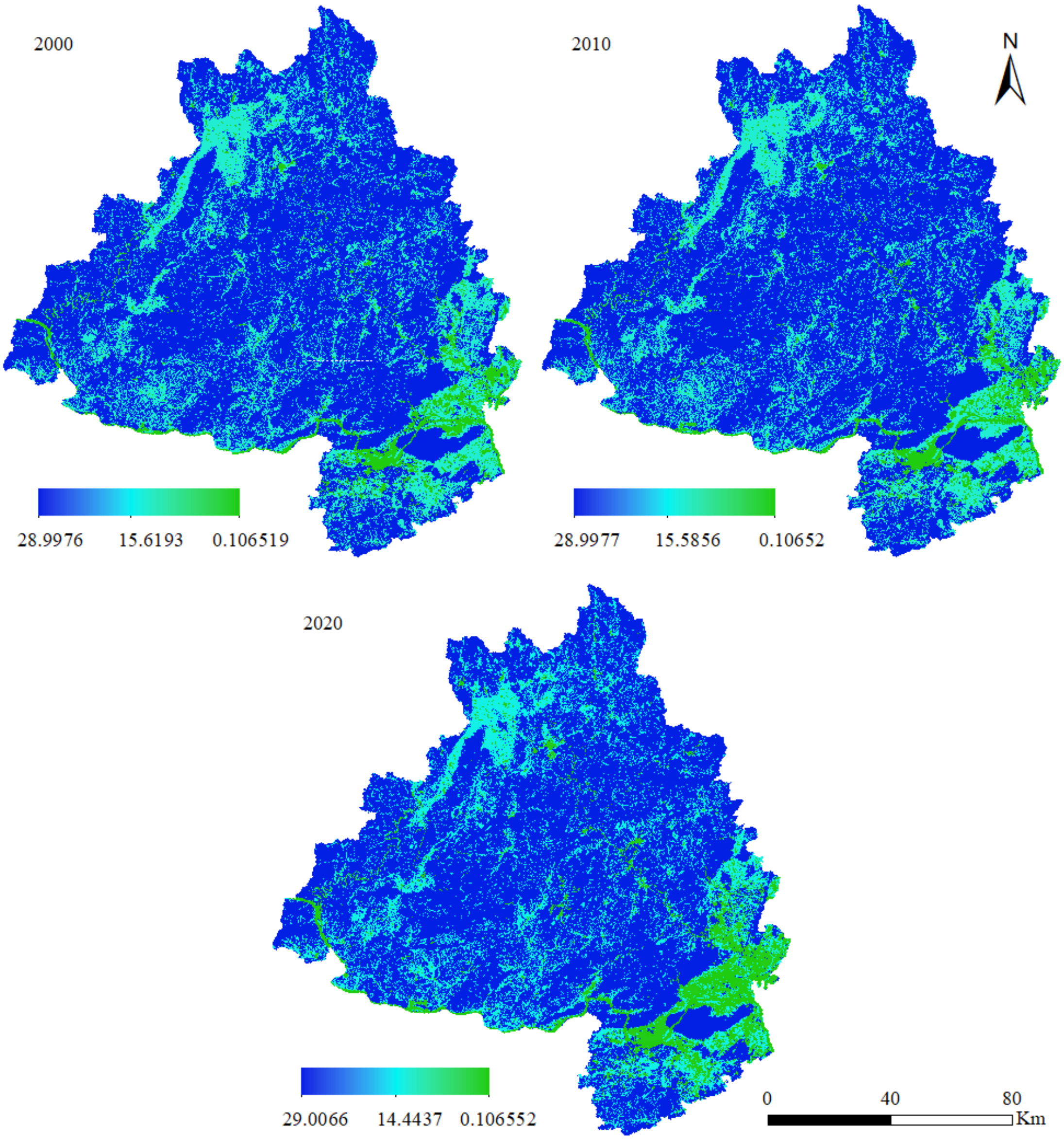

Fig.5 Spatial Distribution of Carbon Reserves in Zhaoqing (unit: t/hm^2)

From a spatial distribution perspective, the carbon reserves in Zhaoqing are distributed in spots, belts, and sheets and the spatial pattern changes are not very obvious (Figure 5). The significant changes in regional carbon storage are concentrated in the southern region, especially in the conversion of construction land, water areas, and cultivated land. High-carbon storage areas are distributed in the central and northern mountainous areas of Zhaoqing. These areas are characterized by high altitude, a large slope, and high forest coverage. Due to the high altitude, the slope and aspect limit the expansion and reclamation of urban land and also affect the vegetation type and soil properties, so that the region can occupy a dominant ecological niche in water conservation, forest resources, and other aspects.

The middle carbon reserves are distributed in the western basin of Huaiji County. The main land cover in this area is cultivated land, which is affected by human activities; thus, the carbon reserves are at the middle level. Low-carbon reserves are distributed in the southern area of Zhaoqing. The area is low in elevation, gentle in terrain, high in urbanization, close to the junction of the Xijiang River and the Suijiang River, and rich in water systems, which are suitable for human social production activities. Numerous fishpond industries are greatly affected by human activities. The main land uses are construction land, water areas, and cultivated land. Therefore, the region's carbon sequestration capacity is relatively weak, and carbon storage remains at a relatively low level.

Table 4 Land Cover Carbon Storage in Zhaoqing from 2000 to 2020

Land Cover Type	2000 Year		2010 Year		2020 Year	
	Carbon Stock/ten thousand t	Proportion /%	Carbon Stock/ten thousand t	Proportion /%	Carbon Stock/ten thousand t	Proportion /%
Cultivated Land	2938.46	9.90%	2844.71	9.58%	2522.61	8.68%
Forest land	24702.61	83.25%	24803.46	83.51%	24606.20	84.70%
Grass Land	1961.11	6.61%	1983.94	6.68%	1818.52	6.26%
Water Area	51.31	0.17%	45.29	0.15%	51.14	0.18%
Construction	20.40	0.07%	22.44	0.08%	51.54	0.18%
Unused Land	0.08	0.00%	0.06	0.00%	0.37	0.00%
total	29673.99	100%	29699.90	100%	29050.38	100%

According to the calculation of the InVEST model, we obtained the trend of the spatial distribution of carbon reserves in Zhaoqing from 2000 to 2010 and 2010 to 2020 (Figure 6). The regions with spatial changes in carbon reserves are characterized by large concentrations and sporadic distributions. Most of the carbon reserves remain basically unchanged, and the changed regions are distributed around the center of Dinghu District. The regions with reduced carbon reserves from 2000 to 2010 were scattered in various regions of Zhaoqing. During this period, urban expansion was slow, and there was no large-scale reduction of carbon reserves.

The regions with increased carbon reserves are scattered in various regions of Zhaoqing, and the regions with the most obvious increase are the regions with rich water systems in Dinghu District, which is related to the conversion of a certain amount of water area into cultivated land. Meanwhile, the Grain for Green policy and the protection of forest land also have an impact on this, which proves that ecological protection policies can increase the carbon reserves of the ecosystem. Most of the terrain in Zhaoqing is low and medium hills, and the nature reserves are also very extensive. The forest land cover is high, the urban expansion capacity is low, and the carbon storage in most areas is relatively stable. The decrease or increase of carbon storage in sporadic distribution may be related to the existence of fast-growing economic forests in Zhaoqing. Small areas of forest land are cut down or fast-growing vegetation is planted.

From 2010 to 2020, the regions with a significant decline in carbon reserves were distributed in the east of Dinghu District, the south-central part of Sihui, and the southeast part of Gaoyao District. During this period, the expansion of construction land was intense. Sihui, Gaoyao District, and Dinghu Districts expanded significantly, and a large amount of cultivated land and a small amount of forest land were converted to construction land. The scope of carbon reserve reduction was consistent with the expansion of construction land. In addition, after 2010, the fishpond industry developed rapidly. In the area with a rich water system in Dinghu District, a large amount of cultivated land was converted into water, and the surface vegetation coverage was reduced, leading to a significant reduction in carbon storage in the area. In general, Zhaoqing City's carbon stock shows a small spatial change. From 2000 to 2010, the carbon stock increased to a certain extent, and from 2010 to 2020, the carbon stock decreased significantly.

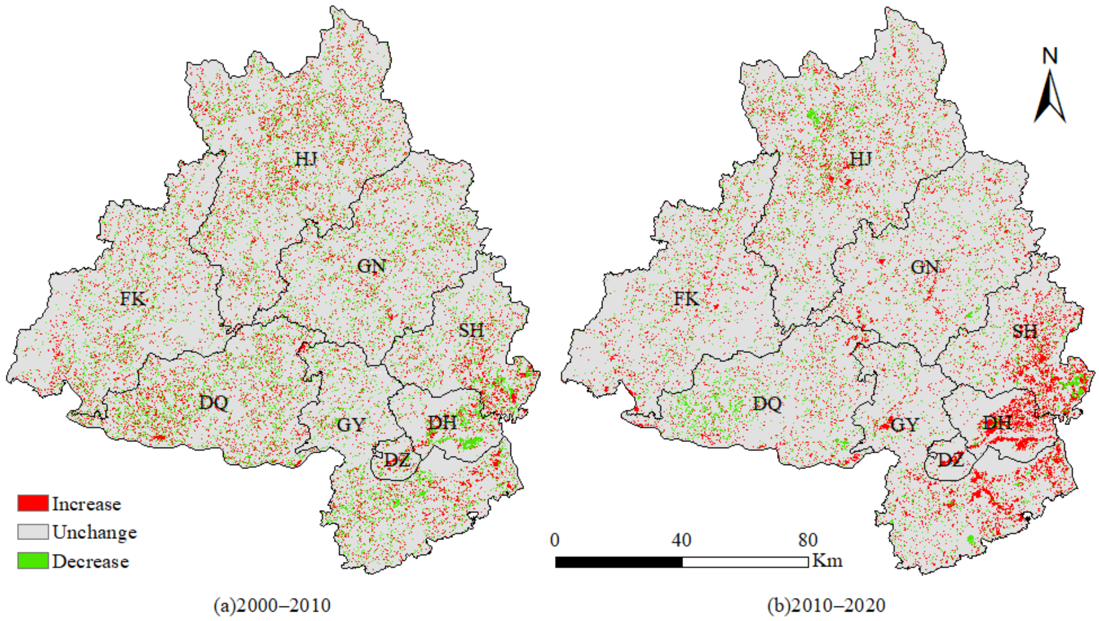

Fig.6 Spatial Distribution of Carbon Reserves in Zhaoqing from 2000 to 2020

4.3 LUCC and Carbon Storage Change

This study uses the land cover stochastic matrix of Zhaoqing from 2000 to 2020 and the carbon density difference between different cover types to calculate the carbon stock change caused by LUCC (Table 5). Data shows that from 2000 to 2010, the LUCC in Zhaoqing led to an increase of 20.12 million tons in total carbon reserves. The transfer of grassland and water areas increased the total carbon storage by 8.2081 million tons and 2.1663 million tons, respectively, accounting for 71.32% and 18.82% of the increase in carbon storage. The transfer of forest land resulted in a significant reduction in carbon storage, totaling 11.3078 million tons, accounting for 86.87% of the total reduction in carbon storage in the entire region. The conversion of forest lands to grassland resulted in a reduction of 8.0144 million tons of carbon storage, accounting for 70.87% of the total carbon storage reduction due to the transfer of forest land. The conversion of grassland to forest land increased carbon storage by 8.3425 million tons, accounting for 70.68% of the total carbon storage increase caused by the conversion of various land covers to forest land.

The above data shows that there is a strong correlation between the conversion of forest land and grassland in terms of carbon storage. The conversion of forest lands to grassland land cover is relatively frequent, which is consistent with the existence of fast-growing economic forests in Zhaoqing. The carbon storage reduced by cutting fast-growing economic forests is supplemented by the carbon storage increased by the formation of grassland after cutting so that the carbon storage is maintained at a relatively stable level for a long time. However, The conversion of cultivated land into forest land, transforming grassland into forest land, the water area being converted into cultivated, forest land, and grassland, and the conversion of construction land to cultivated land and forest land are beneficial for increasing carbon storage. The conversion of cultivated land into water and construction land and the conversion of forest land to various land uses are not conducive to the increase of carbon storage. The carbon storage changes caused by other cover conversions are relatively small.

The change in land cover in Zhaoqing from 2010 to 2020 led to a decrease of 6.5745 million tons in total carbon reserves. The conversion of a large amount of land to construction land, water areas, and forest land is the main reason for the reduction of carbon storage during this period. The transfer of construction land and water has reduced the total carbon storage by 4.2709 million tons and 3.2716 million tons, respectively, accounting for 34.13% and 26.14% of the carbon storage reduction. The transfer of forest land reduced the total carbon storage by 7.9848 million tons, accounting for 63.81% of the reduction in carbon storage. This shows that the rapid expansion of construction land and the rapid development of the mulberry pond industry in Zhaoqing from 2010 to 2020 have led to the conversion of numerous cultivated land, forest land, and grassland to construction land and water areas, leading to a significant reduction in carbon reserves. The conversion relationship between forest land and grassland during this period is consistent with that of 2000–2010, but the conversion area between forest land and grassland is much smaller than that of 2000–2010, which is consistent with strengthening the implementation of environmental protection policies.

In addition, the transfer of construction land and water has broken the relatively stable carbon storage situation caused by the mutual conversion of forest land and grassland from 2000 to 2010. The conversion of cultivated land and grassland to forest land increased the total carbon storage by 1.5757 million tons and 3.4908 million tons, respectively, accounting for 26.53% and 58.77% of the increase in carbon storage. Conversion of cultivated land into forest land, transforming grassland into forest land, converting the water area into cultivated and forest land, and converting construction land to cultivated land are beneficial for increasing carbon storage. Conversion of cultivated land into water and construction land, the conversion of forest land into various land uses, and the conversion of grassland to water areas, and construction land is not conducive to the increase of carbon storage. The carbon storage changes caused by other cover conversions are relatively small.

Table 5 Change of Land Cover Conversion and Carbon Storage in Zhaoqing

Land cover type conversion	2000-2010		Subtotal of changes in carbon storage	2010-2020		Subtotal of changes in carbon storage
	Area /km²	Changes in carbon storage /ten thousand tons		Area /km²	Changes in carbon storage /ten thousand tons	
cultivated - forest	130.27	220.01	66.00	122.58	157.57	-183.97
cultivated - grass	57.33	3.30		27.65	-2.46	
cultivated -water	70.94	-107.92		114.05	-173.01	
cultivated-construction	33.18	-49.39		112.40	-165.89	
cultivated - unused	0.00	0.00		0.11	-0.18	
forest - cultivated	125.83	-212.51	-1130.78	111.24	-129.22	-798.48
forest - grass	491.25	-801.44		276.79	-352.31	
forest - water	28.31	-90.88		42.85	-125.64	
forest - construction	8.13	-25.83		61.73	-185.76	
forest - unused	0.04	-0.11		1.75	-5.55	
grass - cultivated	33.71	-1.94	820.81	39.28	-6.96	237.83
grass - forest	511.36	834.25		296.02	349.08	
grass - water	4.35	-6.87		17.63	-28.36	
grass - construction	2.98	-4.61		45.41	-75.42	
grass - unused	0.02	-0.03		0.30	-0.50	
water - cultivated	56.47	85.89	216.63	18.99	27.18	64.68
water - forest	33.29	106.86		12.65	32.26	
water - grass	14.93	23.56		3.87	4.69	
water - construction	9.75	0.32		24.53	0.55	
water - unused	0.14	0.00		0.60	0.00	
construction - Cultivated	15.59	23.21	47.06	11.77	14.42	22.49
construction- forest	6.02	19.14		2.94	7.00	
construction - grass	3.10	4.80		1.13	1.21	
construction - water	2.84	-0.09		2.07	-0.14	
construction -unused	0.00	0.00		0.05	0.00	
unused - cultivated	0.20	0.30	0.41	0.02	0.00	-0.01
unused - forest	0.03	0.10		0.01	0.01	
unused - grass	0.01	0.02		0.00	0.00	
unused - water	1.59	-0.01		0.40	-0.01	
unused- construction	0.00	0.00		0.01	-0.02	

total	1641.65		20.12	1348.84		-657.45

LUCC and carbon storage in Zhaoqing from 2000 to 2020 (Figure 7) show that the land cover transferred to construction land or water area in the land cover type is consistent with the area of carbon storage reduction. These areas are distributed in the middle of Duanzhou District, the east of Dinghu District, the middle and south of Sihui City, and the southeast of Gaoyao District. The area has a low altitude and flat terrain, making it easy for urbanization and industrialization, and urban construction is relatively rapid. In addition, with the development of numerous mulberry-based fishpond industries in the region after 2010, forest land and cultivated land have been encroached upon and converted into construction land and water, resulting in a significant reduction in carbon storage.

The conversion of land cover types to forest land is consistent with the increase in carbon storage areas, which are distributed in the western part of Deqing County. The terrain of this area is composed of medium to low hills, and the land cover is grassland and forest land. According to the spatial distribution of land cover (Figure 3), from 2010 to 2020, a large amount of grassland in the area was converted into forest land, resulting in a significant increase in carbon storage. In general, there is a certain correlation between land cover types and changes in ecosystem carbon storage. Economic development can find a balance between land planning and management, reduce unnecessary ecological damage, strengthen ecological environment protection, and mitigate the obvious reduction of Zhaoqing's ecosystem carbon storage.

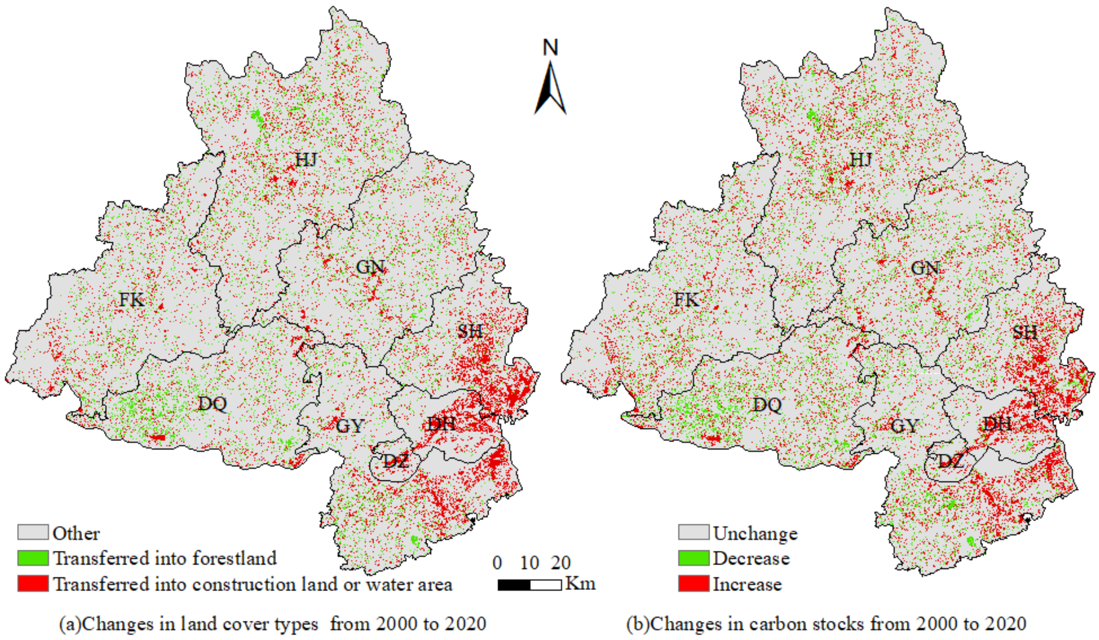

Fig.7 Change of Land Cover Type and Carbon Storage in Zhaoqing

V. CONCLUSION

This paper combines ENVI and ArcGIS software, uses the land cover data of Zhaoqing in 2000, 2010, and 2020, and uses the carbon module of the InVEST model to analyze the carbon storage. It is clear that LUCC has an important impact on the carbon storage of the regional ecosystem, which can provide a decision-making basis for the land use planning and ecological sustainable development of Zhaoqing. The main conclusions are as follows:

(1) From 2000 to 2020, the area of land cover types in Zhaoqing City has not changed much, and the area of cultivated land, forest land, and grassland has decreased, of which the area of cultivated land has decreased the most, with an area of 348.69 km². The area of water area, construction land, and unused land has increased, with construction land increasing the most, with an additional area of 345 km².

(2) The carbon stock values of Zhaoqing in 2000, 2010, and 2020 calculated by the InVEST are 296.74×10^{6}t, 297.00×10^{6}t, and 290.50×10^{6}t. Carbon storage first increased and then decreased, showing an overall downward trend. The total carbon storage decreased by 6.24×10^{6}t, with an average annual reduction of 3.12×10^{5}t.

(3) High carbon storage areas are distributed in the central and northern mountainous areas of Zhaoqing, and the land cover in this area is forest land. The middle carbon storage areas are distributed in the western basin of Huaiji County, where the land cover is cultivated land. Low carbon reserves are distributed in the south of Zhaoqing City, where land cover is construction land and water areas.

(4) The spatial pattern change of carbon storage in Zhaoqing is not very obvious. The obvious change is concentrated in the surrounding area of the central Dinghu District. The expansion of construction land and the mutual conversion of water areas and cultivated land make the carbon storage change in this area more obvious. In terms of land cover type, the area transferred to construction land or water areas is consistent with the area with reduced carbon storage, while the area transferred to forest land is consistent with the area with increased carbon storage.

(5) From 2000 to 2010, the LUCC in Zhaoqing increased the total carbon storage by 20.12 million tons, and the conversion between forest land and grassland kept the carbon storage at a relatively stable level for a long time. From 2010 to 2020, the LUCC in Zhaoqing led to a decrease of 6.5745 million tons in total carbon reserves. Numerous acres of land were transferred to construction and water areas, and forest land was transferred out, which was the main reason for the decrease in carbon reserves in this period.

In general, a balance needs to be achieved between economic development and ecological environment protection. The obvious reduction of carbon storage in the ecosystem of Zhaoqing is due to unreasonable land use and cover types, such as expansion of construction land and water areas, and encroachment of cultivated land and forest land. Through scientific land planning and management, optimizing land use structure, rational planning of urban construction land and aquaculture land, and minimizing negative impacts on the ecological environment while ensuring economic development, these problems can be effectively alleviated to achieve the goal of sustainable development. In addition, the central and northern mountainous areas of Zhaoqing City are covered by a large area of forests, with rich forest land, grasslands and a variety of biological resources, which plays an important role in balancing the change of land cover type in the main urban area due to human activities, resulting in carbon loss, balancing the ecosystem of the entire Zhaoqing region, and slowing down the decline of carbon storage in the ecosystem.

ACKNOWLEDGEMENTS

The author is grateful for the research grants given to Ruei-Yuan Wang from GDUPT Talents Recruitment (No.2019rc098), and ZY Chen from Talents Recruitment of GDUPT (No. 2021rc002), in Guangdong Province, Peoples R China, and Academic Affairs in GDUPT for Goal Problem-Oriented Teaching Innovation and

Practice Project Grant No.701-234660.

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