DOI: 10.23977/erej.2024.080216
ISSN 2616-3756 Vol. 8 Num. 2

Impact of Land Use Change on Carbon Budget in Greater Bay Area

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Keywords: Land Use Change; Carbon Budget; Carbon Emission Coefficient Method

Abstract: Carbon emission is an important cause of current climate warming. Land use (LU) change affects regional carbon emission and carbon absorption, which in turn affects regional carbon budget. This study examines the impact of LU change on carbon budget in the Greater Bay Area (GDHKMGBA) from 1980 to 2020. By calculating the dynamic attitude of LU, various types of land change were analyzed, carbon budget was calculated by carbon emission coefficient method, and temporal and spatial evolution characteristics were analyzed by Moran index, nuclear density analysis, center of gravity and standard deviation ellipse. The results show that: (1) In the past 40 years, the construction land(CL) and water area increased, the cultivated land and forest land decreased, and the land change was significant; (2) The carbon budget showed an increasing trend, mainly due to the increase of CL and the decrease of forest land; (3) The spatial auto-correlation of carbon budget was significant, and the shift trend of the center of gravity was consistent with the center of gravity of carbon emission(GOCE), showing a "northwest - southeast" distribution.

1. Introduction

In recent years, global warming has become one of the focus of global attention, the main cause of global warming is the sharp increase of carbon emissions. Existing studies show that LU change can have an important impact[1,2] on carbon emissions and carbon budget balance by changing the structure and function of the ecosystem. The GDHKMGBA, as the most economically dynamic and innovative city cluster in China, has undergone drastic changes in LU in the context of rapid economic development. However, there are few studies on the impact of LU change on the carbon budget of this area at present.

At present, the research on LU change at home and abroad mainly focuses on the spatio-temporal change[3,4] of LU, the ecological benefit[5,6] of LU, the driving[7,8] force of LU change, etc. In the context of carbon neutrality, more studies have begun to pay attention to the impact of LU on carbon. At present, researches on carbon budget at home and abroad mainly include spatial differentiation[9,10] of carbon budget, research[11] on carbon compensation zoning, carbon budget accounting[12]and spatio-temporal evolution[13] of carbon budget, etc. Studying the spatio-temporal evolution of carbon budget can help to understand the trend of carbon neutrality within a region and formulate carbon neutrality policies suitable for regional development. This paper aims to analyze the impact of LU change on the carbon budget in this area from 1980 to 2020, which will help relevant departments of this area formulate scientific and reasonable land planning and carbon emission policies, so as to promote the reduction of carbon emissions and the realization of carbon neutrality in this area.

2. Reviews and data sources

2.1. Definition

this area is located in the south of China, between 111°12 '~115°35 east longitude and 21°25' ~24°30 'north latitude, and includes all the near cities of Guangzhou. The terrain of the Bay Area is mainly plain, the climate is mainly South Asian tropical climate, the average annual rainfall between 1500 and 2500mm, the average annual temperature is 22.5℃, the main rivers are Beijiang, Dongjiang and Xijiang, the main soil types are paddy and red. This area became a national strategy in 2017. With the Pearl River Estuary, it can quickly go to sea externally and directly reach Guangxi and even Southwest China via the Xijiang River internally. It has a wide radiation range and an advantageous geographical position.

2.2. Data Sources

China Land-Use Cover Changes (CNLUCC) dataset is derived from the Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences (http://www.resdc.cn). The spatial resolution of the dataset is 30 m. The data of LU Cover Changes in 1980, 1990, 2000, 2010 and 2020 were selected in this study.

3. Research Methods

3.1. Single LU dynamic attitude

The dynamic attitude of single LU can reflect the speed or speed of land type change in a certain period of time in a region. The greater the value, the greater the regional LU change[14].

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \tag{1}$$

Where, K refers to the dynamic attitude of LU of a certain land type during the study period; U_a is the quantity of a certain land type in the research base period; U_b is its quantity at the end of the study period; T is the length of the study.

3.2. Calculation of carbon budget

This study uses the carbon emission coefficient method (CECM) to calculate the status of carbon emission and carbon absorption, and then calculates the status[15] of carbon budget. Due to the lack of energy consumption data in this region, it is difficult to obtain long time series data corresponding to LU data. Therefore, this paper mainly calculates the carbon budget of each LU type by applying the CECM. The CE (absorption) amount is calculated by using CEC. The specific calculation formula is shown in (2):

$$C = S_i \cdot E_i \tag{2}$$

In the below formula, when C is positive, CE is denoted as C_p; when C is negative, carbon absorption is denoted as C_x; S_i is the area of different LU types, E_i is the CE (absorption) coefficient of different LU types, emission is positive, absorption is negative. Table 1 shows the CEC of each LU type.

Table 1: Reference table for carbon emission coefficient of land use

Land use Types	Carbon emission factor /(t ·km^{-2} ·a^{-1})	Literature sources
Cultivated Land	42.2	Chang Yoon-sen et[16] al.; Sun Hyuk et al.
Woodland	-57.8	Xing Xiuwei et[18] al.; Ji Xueqiang et al
Grassy	-2.1	Xing Xiuwei et[18] al.; Sun He et al.
Waters	-25.2	Xiao Lei et[20] al.; Ji Xueqiang et al
Land for construction	4297	Sun Hyuk, etc.
unutilized	-0.5	Xiao Lei et[20] al.; Lin Xiaonan et al

The carbon budget status can be expressed by the formula (3) as follows:

$$F = C_p + C_x \tag{3}$$

Where F is the total carbon budget, C_P is the total carbon emission, and C_x is the total carbon absorption.

3.3. Moran Index

Moran index is an important tool to measure spatial correlation, which can be based on the analysis of the spatial distribution characteristics of things or phenomena, reveal their clustering or diffusion patterns in space through visual methods, and analyze the spatial relationship law between research objects. In this paper, the global Moreland index is selected for research and analysis. See (4) for the formula.

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=0}^{n} W_{ij} Z_i Z_j}{S_0 \sum_{i=1}^{n} Z_i^2} \tag{4}$$

Where I represents the global Moran index, n is the observed sample size, Wij is the spatial weight matrix, ZZi representsj the difference between the factors of cities i and j and the average value, where the factors refer to the carbon emissions of each city and the average carbon emissions of cities in this area, and S is the aggregation of all spatial0 weights.

3.4. Analysis of nuclear density

Kernel density analysis is usually used to calculate the density of point elements and line elements in a specific region, which can intuitively reflect the distribution of these discrete measurements in a continuous region.

$$f(x) = \frac{1}{Nh}\sum_{i=1}^{N} K\left(\frac{X_i - x}{h}\right) \tag{5}$$

Through repeated trials, it is found that the spatial pattern of GDHKMGBA can be better described when h= 5000km^2, so h= 5000km^2 is selected in this study.

3.5. Center of gravity and standard deviation ellipse

There is a specific point inside the region where the forces acting on it in all directions balance each other out, and this particular point is called the center of gravity. The standard deviation ellipse usually use to describe the spatial distribution and multidimensional characteristics of the object of study by drawing the ellipse shape using the mean and standard deviation of the data. It can accurately measure the center of gravity (CG), distribution range(DR), spatial intensity, directionality and orientation and their changes of the carbon budget in this area. Its calculation formula is shown below.

Center of Gravity:

$$\bar{x} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i} \tag{6}$$

Azimuth:

$$\tan\theta = \frac{\left(\sum_{i=1}^{n} w_i^2 \tilde{x}_i^2 - \sum_{i=1}^{n} w_i^2 \tilde{y}_i^2\right) + \sqrt{\left(\sum_{i=1}^{n} w_i^2 \tilde{x}_i^2 - \sum_{i=1}^{n} w_i^2 \tilde{y}_i^2\right)^2 + 4\sum_{i=1}^{n} w_i^2 \tilde{x}_i \tilde{y}_i}}{\sum_{i=1}^{n} 2 w_i^2 \tilde{x}_i \tilde{y}_i} \tag{7}$$

X and Y axis standard deviation

$$\sigma_x = \sqrt{\frac{2\sum_{i=1}^{n} (w_i \tilde{x}_i \cos\theta - w_i \tilde{y}_i \ \theta)^2}{\sum_{i=1}^{n} w_i^2}}$$

$$\sigma_y = \sqrt{\frac{2\sum_{i=1}^{n} (w_i \tilde{x}_i \sin\theta + w_i \tilde{y}_i \cos\theta)^2}{\sum_{i=1}^{n} w_i^2}} \tag{8}$$

Ellipse area:

$$S = \pi \sigma_x \sigma_y \tag{9}$$

In the formula, (xi,yi) represents the longitude and latitude geographical coordinates of each prefecture-level city, w represents the carbon budget value of this area, θ represents the azimuth of the ellipse, σx and σy represent the SD of the X-axis and Y-axis of the circle respectively, and S represents the area of the SD ellipse.

4. Analysis of results

4.1. Analysis of LU change

During the study period, forest land and cultivated land dominated the Greater Bay Area, with the proportion of forest land decreasing from 56% to 54%, while the proportion of cultivated land decreased significantly, from 30% to 22%. Relatively speaking, the proportion of water area remained at 7 percent, while the proportion of CL increased significantly, from 5 percent to 15 percent (see Figure 1).

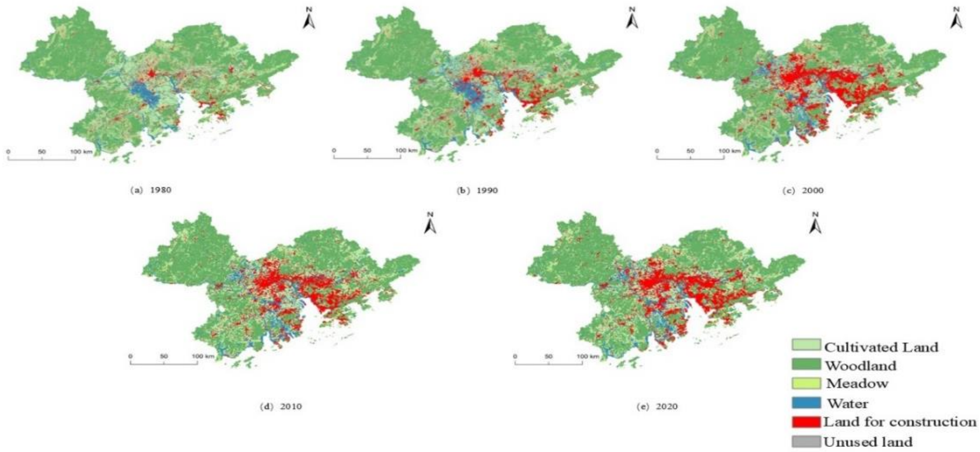


Figure 1: Spatial distribution of land use in the GDHKMGBA, 1980-2020

From 1980 to 2020, the dynamic attitude of single LU for CL and water area was positive, while the dynamic attitude of single LU for cultivated land, forest land, grassland and unused land was negative. The dynamic attitude value of single LU was the largest for CL, reaching 4.87%, and the smallest for unused land, reaching -1.67%. This indicates that the urbanization process of GDHKMGBA accelerated from 1980 to 2020, and the development of unused land was intensified. The single LU dynamic attitude of CL has always been positive, and the value showed an increasing trend year by year from 1980 to 2010. The dynamic attitude of unutilized land was positive in 1980-1990 and negative thereafter, indicating that the Greater Bay Area increased the development of unutilized land after 1990, with the highest value reaching -6.16% from 2000 to 2010(see Table 2).

Table 2: Change of dynamic attitude of single land use in GDHKMGBA during 1980-2020

	1980-1990	1990-2000	2000-2010	2010-2020	1980-2020
Cultivated Land	-0.28%	-0.93%	-1.25%	-0.44%	-0.65%
Woodland	0.00%	-0.09%	-0.19%	-0.12%	-0.10%
meadow	0.04%	-0.39%	-1.01%	0.78%	-0.16%
Water	0.91%	1.30%	-0.56%	-0.23%	0.34%
Land for construction	1.10%	4.22%	6.52%	1.31%	4.87%
Unused land	0.96%	-0.13%	-6.16%	-1.98%	-1.67%

4.2. Analysis of spatio-temporal changes of carbon budget

Over the past 40 years, the region's carbon budget has continued to grow, roughly tripling from 10.025 million tons in 1980 to 34.6526 million tons in 2020. Among them, the largest increase in 2000-2010, 12.511 million tons. At the same time, only the dynamic attitude of CL is positive, and the dynamic attitude of other land use types is negative. The LU rate changes greatly, and the change range of the four LU types is more than 1%. Among them, the CL with the largest change has promoted the growth of carbon emissions, and its single LU has increased by 6.52%, which is also the main reason for the sharp increase in carbon budget.

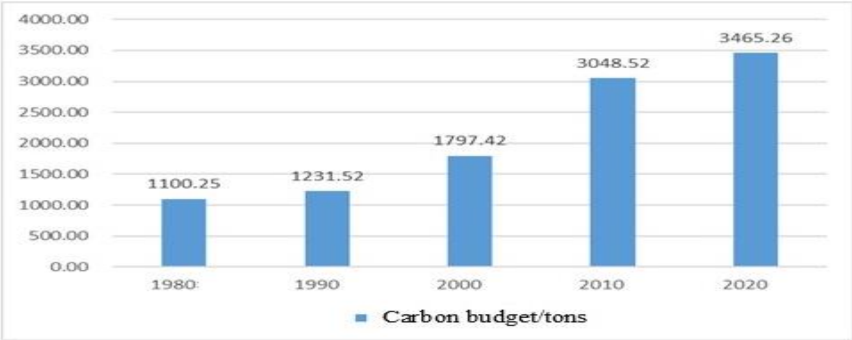


Figure 2: Trend chart of carbon budget change in GDHKMGBA from 1980 to 2020

According to the analysis of Figure 2, the carbon budget of cities in this area showed a trend of gradual increase from 1980 to 2020 except Hong Kong. The carbon budget of Hong Kong increased from 609,000 tons in 1980 to 967,400 tons in 2010, and then decreased to 883,900 tons in 2020. See from Figure 2, the single LU dynamic was -0.82%, while the area of grassland, forest land and water area increased, and began to actively reduce CE. City with the highest carbon budget was Guangzhou, with a carbon budget of 6,518,200 tons. From 1980 to 2020, the LU dynamic attitude (DA) of a single LU was greatly changed, and the change range of other LU types except forest land and grassland was more than 1%, and the CL had the highest DA of 9.11%.

By analyzing the LU change and carbon budget of each city, it is found that the rapid growth of carbon budget is mainly due to the relatively drastic LU change, and the dynamic attitude of single LU change of multiple LU types is more than 1%, which leads to the continuous growth of CL area with carbon emission, while the continuous reduction of forest land, grassland and unused land area with carbon absorption. Take Hong Kong as an example, once the CL area begins to decrease, the forest area increases, and the dynamic attitude change of single LU change of each LU type does not exceed 1%, the carbon budget will decline.

4.3. Analysis of Moreland Index

During the study period, the *Moran's I* index of the overall carbon budget of GDHKMGBA showed significant positive results, ranging from 0.158 to 0.247(see Table 3). The value fluctuated greatly, showing a trend of first decreasing and then increasing, which reflects that the spatial correlation of carbon budget first weakened and then increased during the study period.

Table 3: Moran's I Index of the overall carbon budget in GDHKMGBA during 1980-2020

Year	Global Moran's I Index	Z-value	P value
1980	0.247	2.127	0.033
1990	0.237	2.072	0.038
2000	0.158	1.557	0.119
2010	0.224	1.951	0.051
2020	0.227	1.977	0.048

4.4. Nuclear density analysis

The carbon budget concentration of GDHKMGBA covers Guangzhou City, Foshan City, Huizhou City, Jiangmen City, Zhongshan City, Dongguan City, Shenzhen City and Hong Kong SAR. The study found that the degree of agglomeration in Huizhou was gradually weakened because of the low dynamic LU attitude of CL, which promoted the increase of carbon emissions in Huizhou. During the study period, the dynamic LU attitude of CL ranked the second from the bottom, accounting for 5.50% (see Figure3).

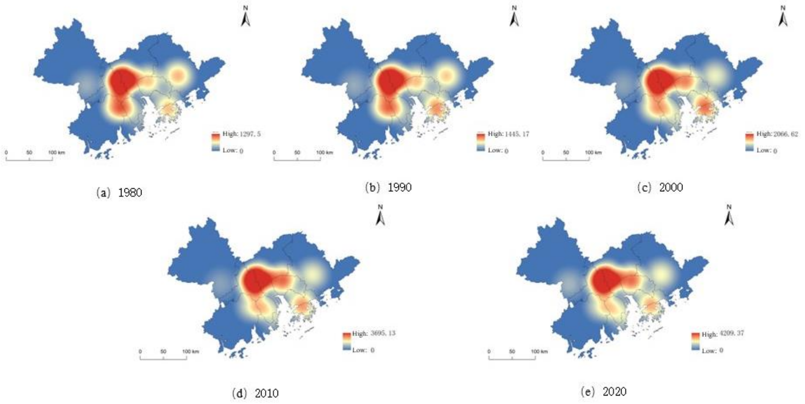


Figure 3: Nuclear density analysis of carbon budget in GDHKMGBA (1980-2020)

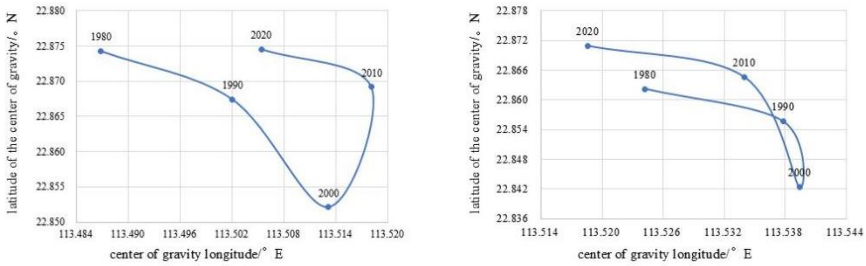
4.5. Standard DE and COG

The area, major axis and minor axis of the standard deviation ellipse(DE) fluctuate and shrink, and the shape gradually flattens. From 1980 to 2020, the rotation angles of the carbon budget ellipses are all greater than 90°, indicating that the carbon budget presents a "northwest to southeast" transverse distribution in this area, covering all the cities around Guangzhou. In the period from 1980 to 2020, the highest ellipse oblate in 1990 was 0.400, that is, the longest and narrowest ellipse, indicating that the east-west division of the carbon budget of Greater Bay Area was the largest. The lowest ellipse oblate in 2000 was 0.377, indicating that the east-west division of the carbon budget of Greater Bay Area was the smallest.

From 1980 to 2020, the carbon budget center of GDHKMGBA was always located in Guangzhou. Table 4 shows that the migration trajectory of the carbon budget center of gravity(COG) in GDHKMGBA can be divided into two stages: the COG shifted to the southeast from 1980 to 2000, and the COG shifted to the northwest from 2000 to 2020. Further research(see Figure 4) shows that the shift direction of carbon budget is consistent with the shift of carbon emission gravity center, indicating that carbon emission is the main factor affecting the spatial change of carbon budget[17]. The reason is that the change amplitude of dynamic attitude of single UL of forest land, grassland and water area affecting carbon absorption is small, while the change amplitude of dynamic attitude of single UL of cultivated land and CL leading to the increase of carbon emission is larger.

Table 4: Ellipse parameters of carbon budget standard deviation from 1980 to 2020

Years	Centroid longitude (°E)	Barycentric latitude (°N)	Major semi-axis (km)	Short half-axis (km)	Azimuth (°)	Oblateness	Area (10,000 km^2)
1980	113.524	22.862	79.02	47.59	91.32	0.398	1.18
1990	113.538	22.856	78.72	47.25	93.91	0.400	1.17
2000	113.539	22.842	75.10	46.80	98.37	0.377	1.10
2010	113.534	22.865	73.66	45.67	96.63	0.380	1.06
2020	113.519	22.871	75.34	45.83	95.59	0.392	1.08



a. Carbon emissions center of gravity trajectory

b. Carbon budget center of gravity trajectory

Figure 4: Trajectory chart of carbon emission and carbon budget center of gravity in GDHKMGBA from 1980 to 2020

5. Conclusions and countermeasures

5.1. Research Conclusions

Using remote sensing data set of UL monitoring in Guangzhou and its surrounding areas from 1980 to 2020, this study analyzed UL change in this region with a single dynamic attitude of UL. Global Moran I index, kernel density, standard deviation ellipse and barycentric analysis were used to analyze the spatio-temporal evolution of the UL carbon budget in the city. The main conclusions are as follows:

(1) In the past 40 years, UL in this area has changed dramatically. The area of CL and water area increased obviously, the area of cultivated land, forest land and unused land decreased year by year, and the change of CL was the most drastic.

(2) From 1980 to 2020, the carbon budget in this region will continue to increase. The rapid growth of carbon budget is mainly caused by UL changes in the past, especially the continuous growth of CL area, which directly leads to the continuous increase of carbon emissions, while the continuous reduction of woodland, grassland and unused land area and the continuous decline of carbon absorption.

(3) The carbon budget of UL showed a significant positive spatial autocorrelation, and the overall trend was first decreasing and then increasing. According to the results of nuclear density analysis, the concentration degree of carbon budget in Huizhou city gradually weakened. The standard deviation ellipse of carbon budget showed a decreasing trend, and both the major and minor axis decreased first and then increased. From 1980 to 2020, the rotation Angle of the carbon budget ellipse is greater than 90 °, showing a "northwest to southeast" transverse distribution. The center of gravity of carbon budget was always in Guangzhou, and the center of gravity shifted to the southeast from 1980 to 2000, and to the northwest from 2000 to 2020, which was consistent with the center of GOCE.

5.2. Countermeasures

With reference to the provisions of the red line for the protection of cultivated land, the red line for forest protection will be formulated to ensure the effective protection of forest land in key ecosystem functional areas and ecologically fragile areas. We will improve relevant laws and regulations on forest land protection and implement differentiated forest land protection policies. In view of the rich ecological value and the natural resources that need to be maintained in Huizhou City and Zhaoqing City[19], more stringent protection measures must be adopted, including but not limited to restrictions on conversion of forest UL and construction activities, or even an official ban[21]. Violations of relevant laws and regulations shall be punished in accordance with the law, and the relevant personnel shall be strictly investigated for legal responsibility.

Acknowledgement

PPJHYLZY-202205, key professional construction project of "Brand Promotion Plan", Zhanjiang University of Science and Technology.

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