Land Use Change and Carbon Emissions in China from 1990 to 2015

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Abstract. Studies of land use changes and the related carbon emission effects have great significance for our understanding of the relationship between land use patterns and carbon emissions. This study indicated that (1) the most significant characteristic of China’s land use change between 1990 and 2015 was the rapid increase in construction land area, reflecting the massive economic development since the reform; (2) after 2000, affected by land remediation, ecological restoration, and land reclamation projects, degraded mining land was transformed into farmland, while villages merged into rural areas, resulting in the conversion of construction land into farmland; and (3) China’s land use types are mainly characterized as carbon sinks. The change process could be divided into two periods, before and after 2000, which may be related to the implementation of ecological construction and restoration projects, such as the Grain-for-Green project. Across China, carbon sources and sinks showed spatial agglomeration, indicating the natural characteristics of different land use types.

1. Introduction
Global change research is a hot topic for scholars [1], and studies suggest that the increase in CO₂ in the atmosphere is the main factor that causes atmospheric warming [2]. Since the industrial revolution, large amounts of fossil fuels such as coal and oil have been burned, leading to increased atmospheric CO₂ levels. In addition, land use changes, especially forest reduction and degradation on a global level, have contributed to increased terrestrial carbon emissions. Energy consumption and carbon emissions from various land use types are considered to be the two major factors facilitating global warming [3].

The Chinese economy has developed rapidly over the past 40 years, entailing increased ecological and environmental problems. The issue of elevated carbon emissions is not only a scientific problem, but also a social and economic topic. Research on carbon emissions has been conducted at local, provincial, and national scales. Statistical data and carbon emission conversion coefficients have been used to obtain changes in total carbon emissions at different levels [4], and the understanding of the underlying processes and mechanisms has greatly enriched our knowledge of carbon emissions [5-6]. Accurate estimates of carbon emission can be achieved through the use of statistical data on energy production and consumption [7]. However, our understanding of the effects of land use change and carbon emissions is constrained by the inaccuracy of land use data and the impacts of land use change processes on natural vegetation. Accurate estimations are therefore difficult to obtain [8].

2. Materials and Methods

2.1. Materials
We used land use data for China with a resolution of 1 km, covering the years 1990, 1995, 2000, 2005, 2010, and 2015. The data set was provided by the Data Center for Resources and Environmental Science, Chinese Academy of Sciences (RESDC) (http://www.resdc.cn). The data was generated based on a 1:100,000 scale land use remote sensing monitoring database.

2.2. Methods

2.2.1. Dynamic degree (K) and Transition matrix
The dynamic degree $K$ was calculated using the following equation:

$$K = \frac{u_b - u_a}{u_a} \times 100\%$$  \hspace{1cm} (1)

where $U_a$ and $U_b$ are the areas of land use types at the beginning and end of the study period, respectively. A positive $K$ value indicates that the area of a certain land use type increases during the research period, while a negative value indicates a decrease. The greater the absolute value of $K$ is, the greater the increase/decrease area changes in a certain land use type.

The transition matrix was calculated using the following equation:

$$\begin{align*}
A_{ij} &= a_{ij} \times 100 / \sum_{j=1}^{n} a_{ij} \\
B_{ij} &= a_{ij} \times 100 / \sum_{i=1}^{n} a_{ij} \\
\text{Change rate} (\%) &= \left( \sum_{i=1}^{n} a_{ij} \right) / \left( \sum_{j=1}^{n} a_{ij} \right)
\end{align*}$$  \hspace{1cm} (2)

where $i$ is the type of land use at the beginning of the study, $j$ is the type of land use at the end of the study, $a_{ij}$ indicates the land use type area, $A_{ij}$ denotes the ratio of the first land use type $i$ in the initial stage of the study and the transformation into land use type $j$ at the end of the study, $B_{ij}$ indicates the proportion of land use type $j$ at the end of the study, converted from land use type $i$ at the beginning of the study.

2.2.2. Land use carbon emission calculation method
The total amount of carbon emissions from a land use type ($Q$) can be calculated as follows:

$$Q = \sum q_i = \sum (A_i \times a_i)$$  \hspace{1cm} (3)

where $q_i$ is the carbon emission of the land use type $i$, $A_i$ is the area of land use type $i$, $a_i$ is the carbon emission factor for the land use type $i$, t/hm$^2$. According to the literature [9-10], cultivated land, forest land, grassland, wetland and unused land emission coefficients are 0.4970, -0.5810, -0.0210, -0.4600, and -0.005 t/hm$^2$.

3. Results

3.1. Land use change
From 1990 to 2015, the change area of construction land in China was the largest, increasing by 63,898 km$^2$, followed by cultivated land and wetland, with increases of 14,939 and 9,248 km$^2$, respectively. Grassland was subjected to the largest reduction, decreasing by 47,264 km$^2$, followed by unused land and forest land, with reductions of 22,392 and 13,923 km$^2$, respectively. From 1995 to 2015, forest land was reduced by 3,5584 km$^2$, while the grassland and wetland areas were decreased by 21,221 and 7,205 km$^2$. In contrast, the area of construction land was subject to increase, with the largest increase of 23,263 km$^2$ from 2010 to 2015. The area of unused land increased only during the period from 1990-1995, with a growth of 39,247 km$^2$ (Fig. 1a).
From 1990 to 2015, the highest dynamic degree of land use was found for construction land (41.01), reflecting that as a result of the reform and the opening of China to the outside world, the country’s economy has developed rapidly, leading to mass migration into cities. To meet the needs of a rapidly growing economy and society, industrial land, residential land, and transportation areas have largely increased. Followed by wetland and cultivated land, the dynamic degrees were 3.52 and 0.84. For grassland, unused land, and forest land with a negative dynamics degree, the absolute values were relatively small, i.e., -1.56, -1.12, and -0.62, respectively. The absolute values of the dynamic degrees of grassland and unused land were higher than that of cultivated land, while that for forest land was lower than that for cultivated land, indicating that grassland and unused land in China declined more rapidly than cultivated land, while the reduction rate of forest land was lower than the increase rate of cultivated land. The dynamic degree of cultivated land was positive in 1995-2000, reaching 2.58. However, in the other four stages, it was negative, with absolute values being less than in 1995-2000 (Fig. 1b).

![Figure 1. Land use change area (a) and dynamic degree (b) at different stages.](image)

A-cultivated land; B-forest land; C-grassland; d-wetland; e-construction land; F-unused land.

3.2. Land use transfer matrix

In general, 2.86% of the cultivated land area (proportion of cultivated land in 2000) were transferred from 2000 to 2015, mainly to forest land, grassland, wetland, and construction land. In terms of forest land, 0.8% of the area were transferred, mainly to construction land, cultivated land, and grassland. Regarding grassland, 1.35% of the area were transferred, mainly to construction land, cultivated land, and forest land, and construction land, while 3.25% of the wetland area were transferred into construction land, cultivated land, and grassland. Of the construction land area, 0.62% were transferred into cultivated land and wetland, while of the unused land, 1.29% of the area were transferred, mainly into cultivated land, grassland, wetland, and construction land (Table 1).

| Stage | Type      | Cultivated land | Forest land | Grassland | Wetland | Construction land | Unused land |
|-------|-----------|-----------------|-------------|-----------|---------|-------------------|------------|
|       | 2000-2015 |                 |             |           |         |                   |            |
| (%)   | Cultivated land | 97.14          | 0.34        | 0.37      | 0.29    | 1.82             | 0.05       |
|       | Forest land   | 0.22           | 99.2        | 0.22      | 0.05    | 0.28             | 0.02       |
|       | Grassland    | 0.61           | 0.27        | 98.65     | 0.1     | 0.18             | 0.2        |
|       | Wetland      | 0.77           | 0.07        | 0.53      | 96.75   | 0.83             | 1.06       |
|       | Construction land | 0.32       | 0.05        | 0.07      | 0.15    | 99.38            | 0.02       |
|       | Unused land | 0.54           | 0.04        | 0.34      | 0.21    | 0.15             | 98.71      |

Columns represent the previous year, rows represent the following year.

The overall probability of land use transfer between 2000 and 2015 in China was low, which was mainly related to the large amount of available land in 2000. After 2000, due to the joint impact of the Grain-for-Green project and other ecological construction and restoration projects, a large area of cultivated land in China was converted into forest land and grassland. At the same time, considerable
amounts of forest land and grassland were transformed into cultivated land. Affected by land remediation, ecological restoration, and land reclamation technologies, degraded land in mining areas was converted into cultivated land through governance, while villages merged into rural areas, leading to the conversion of construction into cultivated land.

3.3. Temporal and spatial changes in carbon emissions from land use change

3.3.1. Characteristics of changes in land use carbon emission

China’s carbon emissions from land use (excluding construction land) were generally negative, which means that the amounts of stored carbon were higher than those of emitted carbon. For the year 1995, we observed the highest amounts of stored carbon, with a total C amount of $6,284.2 \times 10^4$ t. In 2000, stored C was lowest, with only $5,895.5 \times 10^4$ t. The change process from 1990 to 2015 could be divided into four stages. The amount of stored carbon in different land use types increased from 1990 to 2015 and decreased from 1995 to 20000. From 2000 to 2010, it increased, with a subsequent decrease by 2015. Since carbon sinks were derived from the land use type area and the corresponding coefficient, the change process of carbon sinks was in fact synchronized with the changes in land use (Fig. 2).

![Figure 2. Change process of land use carbon emissions in China from 1990 to 2015.](image)

3.3.2. Characteristics of regional differences in carbon emission from land use

Of the carbon emissions from the different land use types, the provinces with high carbon emissions included Shanghai, Tianjin, Hebei, Shandong, Jiangsu, Anhui, Henan, Shanxi, Shaanxi, Chongqing, Ningxia, and Gansu. Other provinces were mainly characterized as carbon sinks. Carbon emissions from land use types or carbon sinks showed obvious spatial agglomeration characteristics, mainly in the northern China Plain and its western area. The area of cultivated land in this region was relatively large, and carbon emissions were mainly derived from cultivated land. Forest land was widely distributed throughout other provinces, acting as a carbon sink (Fig. 3a). Regarding the distribution of carbon emissions from cultivated land, this land use type was the only carbon source. The spatial distribution of carbon emissions from cultivated land also showed agglomeration characteristics. The provinces with the highest emissions were mainly located in the northeastern region, the northern China Plain, and the Sichuan Basin. The latter provinces are located on the Qinghai-Tibet Plateau, northwest and south of China (Fig. 3b). Forest carbon sinks were the smallest C sinks, including the provinces Xinjiang, Qinghai, Ningxia, Gansu, Shanxi, Chongqing, Hebei, Beijing, Tianjin, Henan, Shandong, Anhui, Jiangsu, Shanghai, and Hainan. The provinces with high forest carbon sinks were distributed in the northeastern, southwestern, and southern parts of China, while the forest carbon sinks in the northern and northwestern parts of the country were relatively small (Fig. 3c).
In general, grassland acted as a carbon sink. The spatial distribution of grassland carbon sinks was relatively simple; northwest China and the Qinghai-Tibet Plateau had the highest amounts of grassland (Fig. 3d). Similarly, wetlands mainly represented carbon sinks. Wetland carbon sinks were mainly distributed throughout the Qinghai-Tibet Plateau and the northwestern regions. In addition, due to the large number of lakes in Hubei and Jiangsu, the wetland area in these regions was relatively large (Fig. 3e). Similarly, idle land mainly acted as a carbon sink (Fig. 3f).

Figure 3. Spatial distribution of land use carbon emissions in China.

Based on land use carbon emission data from 1990 to 2015, the average carbon emissions of land use types were calculated and divided into five groups according to their rankings in each province, i.e., 0-20%, 20-40%, 40-60%, 60-80%, 80-100%.

4. Conclusions

(1) From 1990 to 2015, the areas of construction land, cultivated land, and wetland increased throughout China, while the areas of grassland, unused land, and forest land decreased. The
construction land area increased by 63,898 km², while the grassland area decreased by 47,264 km². The dynamics degree of construction land was the highest, reaching 41.01, followed by wetland and cultivated land with 3.52 and 0.84, respectively. The grassland dynamics degree was -1.56, followed by those for unused land and forest land with -1.12 and -0.62, respectively. Land use change in China was predominantly characterized by the rapid growth of construction land area, reflecting the massive economic development of the country since the reform.

(2) After 2000, due to the joint impacts of the Grain-for-Green project and other ecological construction and restoration projects, large areas of cultivated land in China were into forest land and grassland. Also, large areas of forest land and grassland were transformed into cultivated land. Affected by land remediation, ecological restoration, and land reclamation technologies, degraded mining land was converted into cultivated land, while villages merged into rural areas, leading to the conversion of construction land into cultivated land.

(3) Land use types in China are generally characterized as carbon sinks. In this study, the changes process was divided into two periods, namely before and after 2000, which is possibly related to the implementation of ecological construction and restoration projects such as the Grain-for-Green project. Cultivated land represented a carbon source, while forest land, grassland, wetland, and unused land were carbon sinks. Northern and northwestern China were mainly carbon sources, while forest carbon sinks were predominantly distributed in the northeast, southwest, and in Tibet. Grassland carbon sinks were mainly distributed in the central and western parts of the northwestern region of the country and in Tibet. The distribution of carbon sources and sinks across China showed spatial agglomeration, reflecting the natural attributes of land use types and natural changes.

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