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# The influence of rapid urbanization and land use changes on terrestrial carbon sources/sinks in Guangzhou, China

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ABSTRACT

Complex changes in carbon sources and sinks caused by rapid urbanization have been observed with extensive changes in the quantity, structure, and spatial pattern of land use types. Based on the modified Carnegie-Ames-Stanford Approach model and on gray relational analysis, we analyzed the influence of land use changes on carbon sinks and emissions in Guangzhou from 2000 to 2012. The aim was to identify suitable options for built-up land expansion that would allow for minimal carbon losses. The key results were as follows: (1) Built-up land increased by 118.91% in Guangzhou city over the study period, with this expansion taking the form of concentric circles extending around the old Yuexiu district. (2) Carbon emissions over the period of analysis significantly exceeded carbon sink capabilities. The total carbon sink decreased by 30.02%, from $535.40 \times 10^3$ t to $374.6 \times 10^3$ t. Total carbon emissions increased by 1.89 times, from $13.73 \times 10^6$ t to $39.67 \times 10^6$ t; 80% of carbon emissions were derived from energy consumption. (3) There were large differences in the extent of carbon sink losses at different scales of built-up land expansion and land use change. In Guangzhou, the loss of carbon sink is small when cultivated land (though not prime farmland) and water bodies are converted to built-up land on a small scale. The loss of carbon sink is much smaller when grasslands are converted to built-up land on a large scale. However, forested land, which has excellent carbon sink functions, should not be converted. (4) Changes in carbon sinks were mainly affected by natural factors and land urbanization. Changes in carbon emissions were mainly affected by population urbanization, economic urbanization, and land urbanization. (5) To achieve “economical and intensive use of land”, “urban growth boundary” and “ecological red lines” should be determined for government policies on land use management. These factors have great significance for “increasing carbon sinks and reducing carbon emissions” in urban ecological systems.



## 1. Introduction

Increased emissions of $CO_2$ and other greenhouse gases are the main contributors to global warming (Crutzen, 2002). A causal relationship between global warming and human activities has been confirmed through observational data and evidence (IPCC, 2013), with one-third of $CO_2$ emissions resulting from land use changes (IPCC, 2006). Urbanization produces radical changes in the quantity, type, and spatial distribution patterns of land use. Rapid changes from agricultural to non-agricultural use of land have led to changing land use/earth surface cover patterns, and the carbon source/sink functions of different land use types change accordingly. In general, the terrestrial ecosystem should function as a carbon sink; however, this is subject to influences of the natural environment and biological activities, particularly with the present-day context of land use change caused by frequent and intense human activity. As a result, there are significant spatial differences in the distribution of carbon sources/sinks, with differences also emerging in response to environmental change (Li et al., 2009). A number of aspects are of particular research significance for studying ecological processes in urban systems; these include clarifying the mechanisms, characteristics, time-space evolution, and factors influencing carbon sink/carbon sources within city systems, as well as exploring how the selective expansion of built-up land onto other land use types can be carried out with minimal carbon sink losses.

Since the late 1980s, scholars have investigated the influence of land use on carbon sources/sinks. Early research focused mainly on

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carbon storage within cultivated land (Mann, 1986). Later research also considered the influence of the changes between agricultural land and forest land, grassland, and cultivated land on carbon sources/sinks (Davidson and Ackermann, 1993; Houghton, 1995; Gaston et al., 1998). Since 2000, there have been studies of land use-related carbon sources/sinks. Studies considering the effects of land use change on carbon sources/sinks have mainly considered differences in carbon source/sink functions between different land use types (Zhang et al., 2014a,b), the influence of land use changes on carbon sources/sinks on the ecological environment (Long et al., 2014; Konadu et al., 2015; Tao et al., 2015), and the calculation of land use carbon emissions (Hutyra et al., 2011). The carbon source/sink function of terrestrial ecosystems is mainly reflected in the storage, stability, and input/output strength of the carbon pool, with significant differences between different land use types (Liu et al., 2016). In studies of soil carbon pools affected by land use change, it was concluded that soil organic carbon pools and carbon emissions are influenced by the combined actions of climate, physical and chemical soil properties, and human activity (Paustian et al., 2000; Pacala et al., 2001; Were et al., 2015), and that land use changes affect the spatiotemporal distribution of the soil organic carbon pool (Bae and Ryu, 2015).

The influence of urbanization on the regional carbon balance is very important, but the effects of urbanization on terrestrial ecosystems were not studied extensively until the 2000s (Collins et al., 2000; Pickett et al., 2001). Consequently, carbon cycle mechanisms in urban ecosystems are still uncertain. Zhang et al. (2012) argue that land types and the length of time before urbanization are two main factors that determine carbon dynamics. However, there are obvious differences between different kinds of land conversion during the urbanization process. Effective carbon management is necessary to maintain the urban ecosystem (Ye et al., 2014). Land use management methods and government policies and measures will greatly influence whether soil functions as a carbon source or sink (Alicia et al., 2011; Page et al., 2014; Gabarron et al., 2015). Studies of optimized land use structure for low carbon emissions have identified prerequisites for not affecting economic development; these include establishing regional optimal low carbon targets, regulation of land use types, quantities and structures (Chuai et al., 2015; Accorsi et al., 2016), and (through the regional sustainable development approach to eco-environmental modeling) adjustment of industrial structure, urban space layout, and other such factors to improve the regional carbon cycle, promote regional low carbon economic development, and enable sustainable utilization (Liu et al., 2011).

The earliest research on the effects of urbanization on carbon emissions is that of Heil and Wodon (1997), who considered inequities in carbon emissions in the 1990s. Since 2000, research into the effects of urbanization on carbon emissions has become increasingly widespread; key foci have included the effects of urbanization development and economic growth on carbon emissions (Galeotti et al., 2006; Shahbaz et al., 2014; Cao et al., 2016), the level of land use impact on carbon emissions as a result of urbanization (Edward and Matthew, 2010), the influence of urban energy structures on carbon emissions (Garg et al., 2001; Chris, 2007), the influence of urban structure and density on carbon emissions (Peter and Jerry, 2007; Fong et al., 2008), and spatial inequities in carbon emissions between rural and urban areas (Brand and Preston, 2010), among others. Urbanization affects economic development and consequently carbon emissions. Madlener and Sunak (2011) argue that the influence of urbanization on carbon emissions mainly depends on the urbanization level of a country, region, or economy sector. Regional differences are evident in spatial heterogeneity, and there are thus clear spatial differences in the influence of urbanization on carbon emissions (Poumanyvong and Kaneko, 2011). The process of urbanization involves migration from rural to urban areas, increased urban population density, increased levels of consumption, corresponding lifestyle changes, and increased energy consumption; these shifts promote an increase in carbon emissions. However, during the later stages of urbanization, carbon emissions are limited by technological progress, industrial upgrading, and improvement of industrial structures (Sauerbeck, 2001; Lebel et al., 2007).

In conclusion, there has been considerable academic research on the influence of land use on carbon sources/sinks and the specific influence of urbanization. However, there has been less focus on how land use changes lead to carbon sink losses during the process of urbanization, apart from a few research (Svirejeva-Hopkins and Schellnhuber, 2006; Zhang et al., 2014a,b; Yan et al., 2016). In fact, an effective way of reducing carbon emissions is to reduce carbon sink losses resulting from land use changes. China is currently undergoing a period of rapid urbanization and industrialization (Feng et al., 2014). According to statistics of the International Energy Agency, China's greenhouse gas emissions were the world's highest in 2007, with per capita carbon emissions of more than 5% the world average level; about half of global additions to $CO_2$ emissions in this year originated from China (IEA, 2009). Given enormous international pressure to reduce carbon emissions and respond to climate warming, it has become very important to study the space-time evolution process and spatial patterns and mechanisms of land use carbon sources/sinks. In this study, we analyzed spatial patterns of land use change processes in Guangzhou, comprehensively evaluating the effects of urbanization on carbon sources/sinks. We also explored options for selective take-up of different land use types in the process of built-up land expansion, in order to minimize carbon losses.

## 2. Study area

Guangzhou is located in southern China, in the central part of the Pearl River Delta. It lies in the southern part of Guangdong province. Relief is high in the northeast and low in the southwest. The hilly and mountainous northern areas of Guangzhou have extensive forest cover; Baiyun Mountain, known as "The Lung of the City", is a low mountain located in the northeast. The central area comprises a hilly basin, while the southern area is comprised of coastal alluvial plains forming part of the Pearl River Delta. Guangzhou experiences a subtropical maritime monsoon climate, with annual average temperature of approximately 21 °C and small annual average temperature differences. The coldest month is January, while the hottest month is July. Average relative humidity is 77% and annual rainfall is about 1720 mm. Guangzhou city encompasses an area of 7434.4 $km^2$ between latitudes of 22°26′–23°56′N and longitudes of 112°57′–114°3′E. Ecological land cover (forest land, grassland, water areas, and wetland areas) occupies 49.17% of the city's total area. The built-up area extends over 23.24% of the city's total area. Agricultural land uses have gradually shifted towards urban agriculture, with evident urban land use characteristics. Guangzhou city includes the eleven districts of Liwan, Yuexiu, Haizhu, Tianhe, Baiyun, Huangpu, Panyu, Huadu, Nansha, Conghua, and Zengcheng (Fig. 1). At the end of 2012, the population was 12.83 million; 85.02% of this population resides in urban areas. Guangzhou city is a core city within the Guang-Fo metropolitan circle, the Yue-Gang-Ao metropolitan circle, and the Pearl River Delta metropolitan circle.

## 3. Method

### 3.1. Data collection

In this study, land use data (from the years 2000, 2005, 2009, and 2012) was used for interpretation of Landsat TM images. NDVI data