Science of the Total Environment 635 (2018) 26–34

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Influence of land urbanization on carbon sequestration of urban vegetation: A temporal cooperativity analysis in Guangzhou as an example

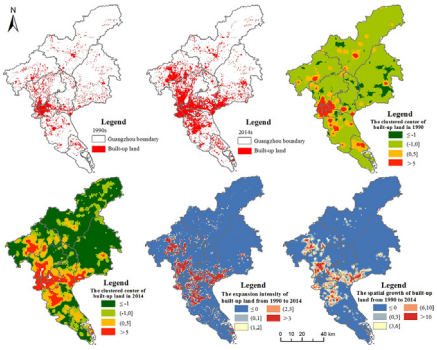
Qian Xu [a,b], Yu-xiang Dong [b,c,*], Ren Yang [b,**]

[a] Guangzhou Institute of Geography, Guangdong Open Laboratory of Geospatial Information Technology and Application, Guangzhou 510070, China
[b] Guangdong Provincial Key Laboratory of Urbanization and Geo-simulation, School of Geography and Planning, Sun Yat-sen University, Guangzhou 510275, China
[c] Xinhua College of Sun Yat-sen University, Guangzhou 510520, China

HIGHLIGHTS

- The city of Guangzhou in China has undergone rapid urbanization.
- No significant temporal lag relationships between land urbanization and carbon sequestration.
- Expansion and spatial agglomeration of built-up land had negative impacts on carbon sequestration of urban vegetation.
- Urban green space and land use management could potentially improve carbon storage.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 19 September 2017
Received in revised form 4 April 2018
Accepted 5 April 2018
Available online xxxx

Editor: R. Ludwig

Keywords:
Land urbanization (built-up land expansion)
Land use change
Carbon sequestration
Temporal sequential cooperativity
Guangzhou city

ABSTRACT

Land urbanization can affect carbon sequestration. In this study, the relationships between land urbanization and carbon sequestration of urban vegetation were studied for Guangzhou, China. The methodology was based on land use data from Thematic Mapper (TM) imagery, MODIS13Q1 data, and climate data, and the improved Carnegie–Ames–Stanford approach (CASA) model and linear system models were employed. Characteristics such as the amount of expansion, spatial agglomeration, spatial expansion intensity, and spatial growth of built-up land were analyzed, and the influence of land urbanization (built-up land expansion) on carbon sequestration of urban vegetation was elucidated by a temporal sequential cooperativity analysis. The main results were as follows. (1) Land urbanization had a clear influence on carbon sequestration of urban vegetation in Guangzhou, and the proportion and spatial agglomeration of built-up land showed significant negative correlations with this carbon sequestration; the correlation coefficients were −0.443 and −0.537, respectively, in 2014. (2) The spatial expansion intensity and spatial growth of built-up land showed small correlations with carbon sequestration, and the correlations from 2000 to 2005 were relatively larger than those at other times; this was because the built-up land expansion speed was the fastest during this period. (3) The temporal sequential cooperativity analysis revealed that carbon was lost as natural surfaces were transformed to artificial surfaces, and land urbanization effects on carbon sequestration showed no significant temporal lag. Carbon sequestration of urban vegetation in the city could be improved by adding urban green spaces; however, this would likely take some time as the system recovers.

* Correspondence to: Y.-x. Dong, Guangdong Provincial Key Laboratory of Urbanization and Geo-simulation, School of Geography and Planning, Sun Yat-sen University, Guangzhou 510275, China.
** Correspondence to: R. Yang, School of Geography and Planning, Sun Yat-sen University, Guangzhou 510275, China.
E-mail addresses: eesdyx@mail.sysu.edu.cn, (Y. Dong), yangren666@mail.sysu.edu.cn. (R. Yang).

https://doi.org/10.1016/j.scitotenv.2018.04.057
0048-9697/

1. Introduction

Urbanization is one of the most significant features of contemporary human societies, and it is an important topic in current geography research (Antrop, 2004). Studies have shown land urbanization to be an important spatial carrier and the most intuitive reflection of the urbanization process (Xu et al., 2016). During the process of rapid urbanization, the types and spatial distribution patterns of land use are severely altered (Liu et al., 2016), and farmland is often converted to non-agricultural land use types. A typical feature of land use change during rapid urbanization is the expansion of built-up land, and such changes may cause changes in the functioning of carbon sequestration in different land use types (Xu et al., 2017).

Land use change has been shown to have an important impact on carbon sequestration and the ecological environment (Long et al., 2014; Tao et al., 2015), and to date, several notable studies have been conducted on this topic. These studies have focused on issues such as the effects of land use change on carbon (Konadu et al., 2015), the influence of land use on soil carbon pools (Pacala et al., 2001), the effects of land use management on carbon sequestration (Gabarrón-Galeote et al., 2015; Page et al., 2014), and the optimized allocation of land use based on the twin goals of increasing carbon sequestration and decreasing carbon emissions (Chuai et al., 2015).

Urbanization is a complex process that is closely related to regional changes in the economic base, industrial structure, residential community, land use, natural resource environment, and so on. In general, during urbanization, the population and non-agricultural activities become concentrated in the city center, there are marked changes in the regional landscape, and the urban culture, urban lifestyle, and associated values spread (Friedmann, 2006). Urbanization significantly affects the regional carbon balance (Strohbach et al., 2012), but detailed studies on the impacts of urbanization on carbon sequestration in terrestrial ecosystems only began in 2000 (Collins et al., 2000; Pickett et al., 2001). Thus, research on carbon dynamics in urban ecosystems (Velasco et al., 2016) and urbanization impacts on carbon dynamics is in its infancy (Zhang et al., 2012); in particular, more mechanistic studies on the urban ecosystem carbon cycle and its changes in response to urbanization need to be conducted. One of the important characteristics of land urbanization is the rapid transformation of farmland to non-agricultural land use types and other changes in surface coverage. Accordingly, carbon sequestration in different land use types changes (Bae and Ryu, 2015; W. Zhang et al., 2014). Frequent and intense human activity is known to change the original nature and function of the natural ecosystem carbon pool (Churkina, 2012; Grimm et al., 2008).

The effects of urbanization on carbon sequestration in relation to land use are still uncertain (Yan et al., 2016). On the one hand, built-up land expansion during the process of urbanization is known to be associated with the transformation of large amounts of natural land use types with high carbon sequestration functionality (cultivated land, forest land, grassland, etc.) into built-up land with low carbon sequestration functionality, thereby causing overall carbon losses from carbon sequestration areas (Konadu et al., 2015; Long et al., 2014; Tao et al., 2015). On the other hand, the carbon sequestration functionality of the urban ecosystem itself should not be ignored. During the transformation of land use types, the carbon stock of the urban ecosystem may enter a carbon accumulation stage after the initial sharp decrease in carbon storage, and new processes may start to compensate for previous carbon losses as a new carbon dynamic balance is reached. Zhang et al. (2012) argued that the carbon pools of ecosystems in developed cities can be similar to those of farmland. Churkina et al. (2010) argued that the ecosystem carbon density of developed cities is unexpectedly the same as that of tropical rain forests. However, it should be noted that the temporal sequential cooperativity relationships between land urbanization and urban carbon sequestration are highly complex and uncertain. Hence, research on the effects of these relationships as well as on the influencing mechanisms would be worthwhile.

Urbanization can affect many aspects of a city such as the population, economy, and land, but the influence of urbanization on carbon sequestration of an urban ecosystem will be mainly related to the land use change process that involves the conversion of farmland to non-agricultural land use types, built-up land expansion, and other types of land use change (Liu et al., 2016), i.e., the influence of land urbanization. The expansion process of built-up land can change the structure and function of regional ecosystems and influence carbon cycle processes; corresponding effects on the carbon sequestration function of ecosystems are widely regarded as being global in scale and a net source of carbon-based greenhouse gas emissions. In response to these changes, scholars have performed numerous studies on the effects of land use change on carbon sequestration. However, specific details on important urbanization characteristics such as the amount of expansion, spatial agglomeration patterns, spatial expansion intensity, and spatial growth of built-up land (built-up land expansion) and their corresponding influence on urban carbon sequestration are needed, in addition to studies on the temporal sequential cooperativity relationships between land use change (land urbanization) and carbon sequestration of urban vegetation. Research on the temporal sequential cooperativity relationships between land use change and city carbon sequestration could enrich our understanding of the evolution of land use carbon effects of regional urbanization, reveal the coupling mechanisms between land use and carbon sequestration, complement theoretical research on urban ecosystem land use carbon effects, and provide data to support land use planning efforts to foster low-carbon cities and reduce carbon emissions.

In this study, these relationships are analyzed for Guangzhou City, which is a highly urbanized area in China. With land use data from Thematic Mapper (TM) imagery, Moderate Resolution Imaging Spectroradiometer (MODIS) normalized difference vegetation index (NDVI) data, climate data, and so on, this study expounds the land urbanization (e.g., built-up land expansion) influence on carbon sequestration of urban vegetation during the rapid urbanization process in the city and analyzes the temporal sequential cooperativity relationships between land urbanization and carbon sequestration of urban vegetation.

2. Study area and methods

2.1. 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 km2 between latitudes of 22s26′–23°56′ N and longitudes of 112°57′–114°3′ E. Ecological land cover (forest land, grassland, water areas, and wetland areas) occupies 41.67% of the city's total area. The built-up area extends over 25.44% of the city's total area (2014). Agricultural land uses have gradually shifted toward 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 2014, the population was 13.08 million; 85.43% of this population resides in urban areas. Guangzhou city is a core city within the Guang-Fo metropolitan circle, the Yue-