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Environmental degradation in the urban areas of China: Evidence from multi-source remote sensing data

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ABSTRACT

The rapid and timely evaluation of urban environmental change is highly important for understanding urban sustainability in China. However, the comprehensive understanding of urban environmental change in China based on multi-source remote sensing data remains inadequate because current studies have mainly focused on a single aspect of the urban environment using a specific source of remote sensing data. In this study, we developed a comprehensive evaluation index (CEI) combining the remote sensing data of the fine particulate matter ($PM_{2.5}$) concentration, land surface temperature (LST) and vegetation cover (VC) to assess the urban environmental change in China at the national scale, among urban agglomerations and across the rapidly urbanized regions. We found a trend of environmental degradation in the urban areas of China between 2000 and 2012. Environmentally degraded and moderately degraded urban areas accounted for 48.14% of the total urban area in China. In particular, the expanded urban areas exhibited the most extensive environmental degradation, with 52.33% of the total expanded urban areas from 1992 to 2012 exhibiting environmental degradation or moderately environmental degradation. The increase in the $PM_{2.5}$ concentration was one of the main manifestations of the environmental degradation in the expanded urban areas. We suggest that more attention should be paid to urban environmental issues during future urban development in China.

1. Introduction

China has experienced unprecedented and rapid urbanization over the last three decades (Bai et al., 2014). From 1981 to 2012, the urban population increased by 2.54 times, from 201 million to 712 million (National Bureau of Statistics of China, 2013). The built-up area increased from 7438 km^2 in 1981 to 40,058 km^2 in 2010, with an annual growth rate of 9.26% (Ministry of Housing and Urban-Rural Development, 2012). In addition to rapid urbanization, urban areas in China have been facing increasing environmental pressure, and various environmental issues have emerged. Studies have shown that in the context of rapid industrialization and urbanization, the quality of natural resources in urban areas has degraded over the last several decades (Cumming et al., 2014; McDonnell and MacGregor-Fors, 2016; Seto et al., 2012). Examples included the decline of vegetation cover (VC) in China's urban areas (Sun et al., 2011), the loss of natural habitats due to urban expansion (He et al., 2014), the deterioration of urban soil quality (Teng et al., 2014; Yao, 2016), the shortage of freshwater supplies in large cities (McDonald et al., 2011), the pollution of urban rivers (Qu and Fan, 2010) and groundwater (Coulon et al., 2016), and increased urban heat island effects (Yang et al., 2011) and fine particulate matter ($PM_{2.5}$) in urban areas (Han et al., 2015). In addition, China has become the largest urban solid waste generator in the world (Geng, 2012; Yang et al., 2016). Rapid urbanization has also contributed considerably to exacerbating warming in China (Sun et al., 2016). According to a recent government plan, the proportion of the Chinese population residing in urban areas will increase from 52.6% in 2012 to 60% by 2020, with an annual growth rate of 1% (Bai et al., 2014). Given the rapid urban development in this country, a timely and accurate evaluation of urban environmental change is highly important to ensure urban sustainability.

Urban sustainability is an adaptive process of maintaining balance between ecosystem services and human wellbeing within and beyond the urban areas. It includes three dimensions: environment, society and economy (Wu, 2010). Urban environment, in a narrow sense, refers to the natural environment within urban areas, including air, soil, water, habitat and biodiversity (Forman, 2014). Urban environment plays a fundamental role in affecting urban sustainability because the degradation of urban environment can be irreversible and cannot be fully

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Table 1
Studies on evaluating urban environmental change in China based on remote sensing data.

Urban environment	Data/sensor	Study area	Time period	Reference
Urban heat island	MODIS LST	419 global large cities	2003–2008	Peng et al. (2011)
NO_x concentration	GOME	China	1996–2010	Zhang et al. (2012)
Vegetation cover	NOAA/AVHRR NDVI	117 Chinese cities	1982–2006	Sun et al. (2011)
Vegetation cover	SPOT/VGT	Yangtze River Delta	2012	Li et al. (2014)
Urban heat island	Landsat TM thermal band	Beijing	1997	Jiang et al. (2006)
Water quality	Landsat TM 7 bands	Shenzhen	1988–1996	Wang et al. (2004)

substituted by economic development (Wu, 2010). Therefore, a set of indices has been developed to gauge the urban environmental change (see Huang et al., 2015 for a review), including theme-based sustainability framework developed by United Nations Commission on Sustainable Development (UNCSD), ecological footprint (EF), green city index (GCI), environmental performance index (EPI), genuine progress indicator (GPI), and human development index (HDI). However, most of these indices need a plethora of data based on census and cannot provide a spatially explicit pattern of urban environmental change.

Remote sensing data offer an effective and spatially explicit alternative to evaluate urban environmental change from local to global scales (Sutton, 2003). Remote sensing can obtain the information of observed objects or region without physical contacts, usually from sensors aboard satellites or aircrafts. Recently, a number of studies have been conducted to evaluate various aspects of urban environmental conditions using different types of remote sensing data (Table 1, Gong, 2012). However, these studies mainly focused on a single dimension of the urban environmental condition and are insufficient to provide a comprehensive picture of urban environmental change in China. Therefore, developing an integrated index which solely needs multi-source remote sensing data can provide a complementary means to evaluate urban environmental change.

The objective of this study is to comprehensively evaluate the urban environmental changes, i.e., the changing environmental conditions in China's urban areas based on multi-source remote sensing data. To achieve this goal, we first developed a comprehensive evaluation index (CEI) of the environmental condition that integrated multi-source remote sensing data of the $PM_{2.5}$ concentration, land surface temperature (LST) and VC. Then, we evaluate the performance of this index on measuring urban environmental change by comparing its results with other common indices based on census data. Finally, we examined the urban environmental changes in China between 2000 and 2012. Our findings represent the latest comprehensive understanding of urban environmental change in China over the last 13 years and will support sustainable urban development in this country.

2. Study area and data

2.1. Study area

Our study focused on the urban areas in China. In this study, the urban areas refer to the areas dominated by the built-up land, which is smaller than a city's administrative boundary but larger than its impervious surface (Liu et al., 2014). We analyzed the environmental changes in the urban area of China at three scales, the national, the urban agglomeration and the rapidly urbanized region scales (Fig. 1). Urban agglomerations are the major engine of urbanization in China. The rapidly urbanized regions are the counties in which the urban

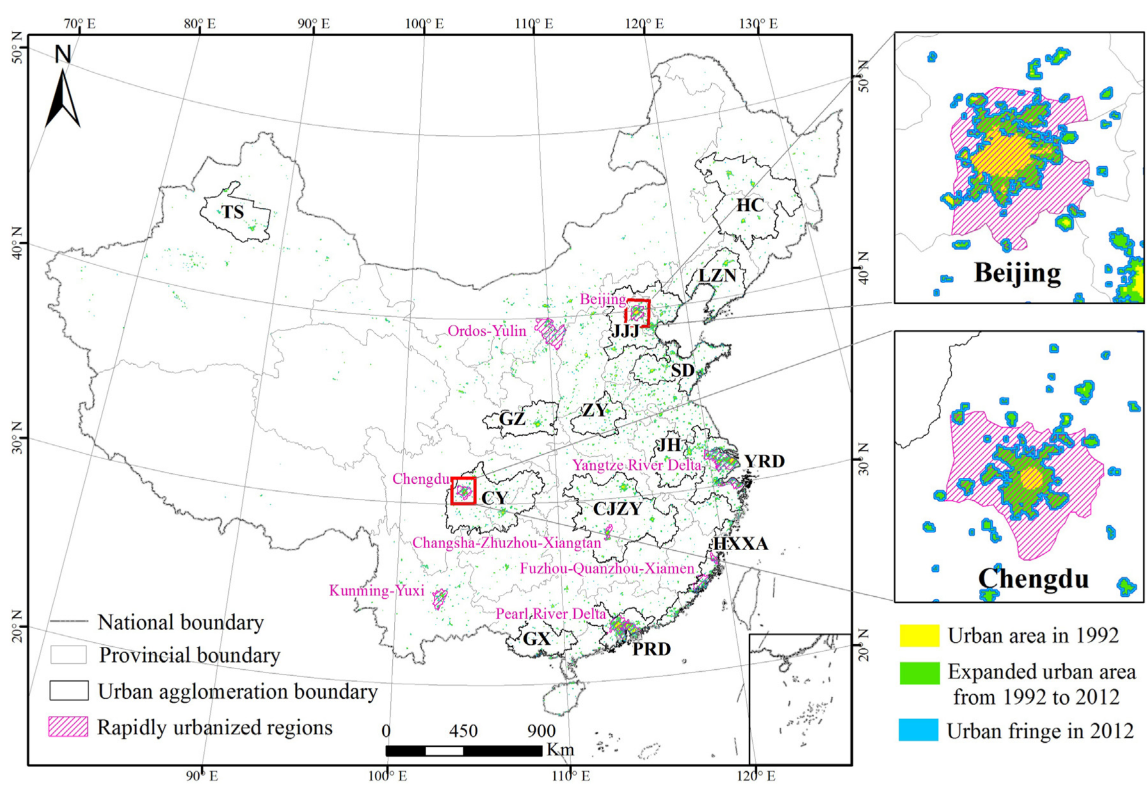

Fig. 1. Urban expansion in China from 1992 to 2012. Note: Abbreviations for the 14 urban agglomerations: Jing-Jin-Ji (JJJ), Liaozhongnan (LZN), Hachang (HC), Shandong peninsula (SD), Jianghuai (JH), Yangtze River Delta (YRD), Haixiaxian (HXXA), Changjiangzhongyou (CJZY), Pearl River Delta (PRD), Guangxi (GX), Chengyu (CY), Guanzhong (GZ), Zhongyuan (ZY), and Tianshanbeipo (TS).