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Research paper

Relationship between land surface temperature and spatial pattern of greenspace: What are the effects of spatial resolution?

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HIGHLIGHTS

- ► We examined the effects of spatial resolution on relationship between LST and urban greenspace.
- ► Landscape metrics of greenspace varied by spatial resolution.
- ► Relationship between LST and abundance of greenspace was consistent across spatial resolution.
- ► Relationship between LST and spatial configuration of greenspace varied by spatial resolution.

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ABSTRACT

Urban heat island (UHI) is a worldwide phenomenon, which causes many ecological and social consequences. Urban greenspace can decrease environmental temperature and thus alleviate UHI effects. Spatial pattern of greenspace, both composition and configuration, significantly affects land surface temperature (LST). Results from previous studies, however, showed inconsistent, or even contradictory relationships between LST and spatial pattern of greenspace, suggesting these relationships may be scale dependent (sensitive to spatial resolution). But few studies have explicitly addressed this issue. This paper examines whether the spatial resolution of the imagery used to map urban greenspace affect the relationship between LST and spatial pattern of greenspace, using Beijing, China as a case study. Spatial pattern of greenspace was measured with seven landscape metrics at three spatial resolutions (2.44 m, 10 m, and 30 m) based on QuickBird, SPOT, and TM imagery. LST was derived from thermal band of Landsat TM imagery. The relationship between LST and spatial pattern of greenspace was examined by Pearson correlation and partial Pearson correlation analysis using census tract as analytical unit. Results showed that landscape metrics of greenspace varied by spatial resolution. Imagery with higher spatial resolution could more accurately quantify the spatial pattern of greenspace. The relationship between LST and abundance of greenspace was consistently negative, but the relationship between LST and spatial configuration of greenspace varied by spatial resolution. This study extended our scientific understanding of the effects of spatial pattern, especial spatial configuration of greenspace on LST. In addition, it can provide insights for urban greenspace planning and management.

1. Introduction

Urban heat island (UHI) describes the phenomenon that temperatures are higher in urban areas compared to surrounding rural areas. It is one of the research focuses in urban climatology and urban ecology because increasing temperatures in the urban area may lead to significant ecological and social consequences (Huang, Zhou, & Cadenasso, 2011; Jenerette, Harlan, Stefanov, & Martin, 2011; Lai & Cheng, 2009; Weng & Yang, 2006). Generally, there are two types of UHI: Air temperature UHI and surface temperature UHI. The air temperature UHI has high temporal resolution with extensive time coverage, which can effectively describe the temporal variation of UHI, but fails in depicting the spatial variation of UHI. This shortcoming of air temperature UHI can be solved using surface temperature UHI, which can provide continuous and simultaneous surface temperature of an entire city (Weng, 2009). Land surface temperature (LST) retrieved from infrared remote sensing imagery has been widely applied to study the spatial pattern of UHI and its relationship with landscape pattern (Cao, Onishi, Chen, & Imura, 2010; Li, Zhou, Ouyang, Xu, & Zheng, 2012; Weng, 2009; Zhou, Huang, & Cadenasso, 2011).

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Considerable research on the relationship between LST and urban greenspace has demonstrated that urban greenspace has cooling effects on LST (Jenerette et al., 2007; Ma, Kuang, & Huang, 2010; Weng, Lu, & Schubring, 2004; Zhou, Huang, & Cadenasso, 2011). It has become widely accepted that increasing greenspace (for example planting more trees) can mitigate UHI (Bowler, Buyung-Ali, Knight, & Pullin, 2010; Li et al., 2012; Zhou, Huang, & Cadenasso, 2011; Weng et al., 2004). However land for urban greening is usually limited. Consequently, there is increased interest in the effects of the spatial configuration of greenspace on LST (Li et al., 2011, 2012; Zhou, Huang, & Cadenasso, 2011). In addition to the increase in greenspace cover, can the management of the spatial configuration of greenspace further mitigate excess heat? A proliferation of studies have shown that the spatial configuration of greenspace (such as that measured by patch density and edge density) significantly affected the magnitude of LST (Li et al., 2011, 2012; Liu & Weng, 2009; Yokohari, Brown, Kato, & Moriyama, 1997; Zhang, Zhong, Feng, & Wang, 2009; Zhou, Huang, & Cadenasso, 2011). The relationship between LST and spatial pattern of greenspace, however, were not consistent. For example, a negative relationship between LST and patch density was reported in Shenzhen and Shanghai, China (Li et al., 2011; Li, Zhao, Miaomiao, & Wang, 2010), but a positive relationship was found in Beijing, China (Li et al., 2012).

These studies used remotely sensed image data with different spatial resolutions to obtain maps of greenspace, based on which the spatial pattern of greenspace was measured. The measurement of spatial pattern of greenspace, and its relationship to LST, may be influenced by the spatial resolution of the imagery (Townsend, Lookingbill, Kingdon, & Gardner, 2009; Vannier, Vasseur, Hubert-Moy, & Baudry, 2011). For example, the relationship between LST and vegetation fraction or NDVI was strongest at 120 m resolution in Indianapolis City, USA (Weng et al., 2004). Liu and Weng (2009) suggested that 30 and 90 m were the optimal resolution to study the relationship between LST and landscape pattern at class level and landscape level, respectively. However, seldom studies reported the influence of spatial resolution on the statistical relationship between LST and the spatial configuration of greenspace.

The overarching goal of this study is to examine the effects of spatial resolution on the relationship between LST and the spatial pattern of greenspace. Specifically, this study addresses two questions: (1) how does spatial resolution of the image affect the measurement of spatial pattern of greenspace ? and (2) is the relationship between LST and the spatial pattern of greenspace consistent across spatial resolutions? We conducted this research in the Beijing metropolitan area, China. Three types of images, with spatial resolution ranging from high (QuickBird and SPOT) to medium (Landsat TM) were used to derive greenspace maps. We examined how landscape metrics varied by spatial resolution, and how their relationships with LST retrieved from the thermal band of Landsat TM imagery varied.

2. Methods

2.1. Study area

Beijing is located in the northeast of the North China Plain (39°28′–41°25′ N, 115°25′–117°30′ E). Its climate belongs to the warm temperate zone with a continental monsoon climate. Beijing displays apparent seasonal periods with a hot and rainy summer and a cold and dry winter. Its annual average temperature is 12.3 °C and annual precipitation is approximately 572 mm. Beijing has a long history and has been the capital city of China for more than 850 years. It experienced rapid urbanization after the implementation of the Reform and Open Policy in 1978. Its population increased from 8.72 million in 1987 to 19.62 million in 2010 and the urbanization level (i.e., percent of urban population) increased from 55% to 86% (Beijing Municipal Statistical Bureau, 2011). Along with rapid urbanization came the increase in the intensification of the UHI effects (Liu, Ji, Zhong, Jiang, & Zheng, 2007)

This study was conducted within the fifth ring road of Beijing (Fig. 1). This is the most developed area in Beijing, with high impervious fraction and intensive UHI (Xiao et al., 2007, 2008). This area is flat with elevation ranging from 20 to 60 m above sea level. The study area included 109 census tracts, which are totally within or have a considerable portion (>30%) within the fifth-ring road (Fig. 1). The census tract was chosen as the analytical unit in the statistical analysis because it is the smallest administrative district, and the majority of local planning and management measures are designed and implemented at this level.

2.2. Spatial pattern of greenspace

Urban greenspace is generally highly fragmented therefore relatively fine-scale resolution remote sensing data are necessary to quantify the spatial pattern of urban greenspace (Zhang et al., 2009; Zhou, Huang, Pickett, & Cadenasso, 2011). We only considered remote sensed images with spatial resolution equal to or higher than 30 m (i.e., the spatial resolution of the most frequently used Landsat TM data). We did not use a downscaling approach (e.g., majority rule) to generate a series of greenspace maps with different spatial resolutions (Alhamad, Alrababah, Feagin, & Gharaibeh, 2011; Liu & Weng, 2009; Wu, 2004). Previous studies found the commonly used aggregation algorithms for downscaling may not precisely simulate landscape spatial pattern as those derived directly from remote sensed images (Saura, 2004). In this study, different types of remote sensing data were selected to generate greenspace maps at different spatial resolutions. We used three kinds of imagery: (1) QuickBird imagery acquired on July 5 2002 with a spatial resolution of 2.44 m (multi-spectral band), representing the image type of very high spatial resolution; (2) SPOT imagery collected on September 8 2004, with a spatial resolution of 10 m (multi-spectral band) representing the image type of high spatial resolution; (3) Landsat TM obtained on October 4 2004, with a spatial resolution of 30 m, representing the most frequently used image type of medium spatial resolution. All the image data were co-registered to a 1:10,000 scale topographic map. Due to data availability, we were not able to acquire QuickBird imagery in the same year as that of SPOT and TM, but its impacts shall be minor because changes in urban greenspace in our study area were very small during 2002–2004. Our study area is located in a highly urbanized area and no significant land use and land cover change took place during our study period.

In this study, greenspace was defined as the vegetated areas, and was mapped from the selected imagery using an object-based classification method with the Feature Extraction tool in ENVI 4.6 (Li et al., 2012). Three types of greenspace maps with different spatial resolutions (i.e., 2.44 m, 10 m, and 30 m, hereafter refer to as QuickBird map, SPOT map, and TM map, respectively) were generated (Fig. 2). The classification accuracies were checked based on 150 randomly selected points, using reference data that were visually interpreted from the QuickBird images. The classification accuracies were 88%, 89.33%, and 78.67%, for QuickBird map, SPOT map, and TM map, respectively. These maps were extracted by census tract to obtain a greenspace map for each census tract.

Landscape metrics are versatile and widely used to measure landscape pattern (McGarigal et al., 2002). Seven landscape metrics were selected to measure spatial pattern of greenspace based on principles such as theoretically and practically important, easily calculated, interpretable, and little redundancy (Li & Wu, 2004; Li et al., 2012; Riitters et al., 1995). The selected landscape