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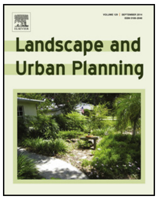

Research paper

Spatial configuration of anthropogenic land cover impacts on urban warming

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HIGHLIGHTS

- Local Moran's *I* index was used to characterize spatial pattern of anthropogenic land cover.
- Composition and spatial pattern of buildings have minimal impact on land surface temperature (LST).
- Spatial patterns of paved surfaces have significant effects on LST.
- We controlled for land cover compositions and quantified relationships between the spatial arrangement of paved surfaces and LST.
- Clustered patterns of paved surfaces elevate LST and the magnitude of its impacts varies for landscapes with different land cover compositions.

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ABSTRACT

Anthropogenic land cover types greatly influence the urban heat island (UHI) effects. This study examined effects of composition and spatial pattern of anthropogenic land cover features on land surface temperature (LST) in Phoenix, Arizona, USA, using a land cover map derived from high resolution satellite data and ASTER LST data. The spatial pattern of land cover features was measured by local Moran's *I*—a continuous spatial autocorrelation index, which can effectively describe dispersed or clustered patterns of land cover features. Our results showed that the composition and spatial pattern of buildings have minimal impacts on LST, while those of paved surfaces alter LST more drastically. The local Moran's *I* of paved surfaces have a stronger positive correlation with nighttime ($r^2 = 0.38$) than daytime ($r^2 = 0.17$) temperatures, suggesting that clustered paved surfaces create stronger warming effects at night. We further controlled for land cover compositions to minimize their effects on LST, and found that the magnitude of warming effects caused by clustered paved surfaces differed among landscapes of varying land cover compositions. Correlations between local Moran's *I* of paved surfaces and LST becomes stronger when paved surface fraction exceeds 50%. These results illustrated aggregate warming effects of clustered paved surfaces, and provide insights on UHI mitigation for land managers and urban planners.

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1. Introduction

Urbanization is a process of altering natural surface materials with manmade features. The anthropogenic alterations of natural surfaces significantly change the energy balance in cities and affect the urban thermal environment (Hart & Sailor, 2009). As a result, urbanization leads to urban heat island effect (UHI)—a phenomenon of higher temperatures in urban areas relative to surrounding rural areas. The UHI impacts human comfort and health, energy consumption, and water use (Brazel et al., 2007). Several studies reported that heat-related deaths were projected to increase due to a warming climate, population growth, and aging (Hajat, Vardoulakis, Heaviside, & Eggen, 2014; Li, Horton, & Kinney, 2013; Sheridan, Allen, Lee, & Kalkstein, 2012). As The United Nations (2013) reported, an additional two billion population will reside in urban areas by 2050, so building sustainable cities plays an important role in achieving global sustainability targets. Thus, UHI mitigation strategies should be incorporated into future city design and planning to minimize negative effects caused by the UHI.

A significant number of studies have investigated relationships between land surface temperature (LST) and the proportion of land cover features (Li et al., 2011; Liu & Weng, 2008; Myint, Wentz, Brazel, & Quattrochi, 2013; Weng, Lu, & Schubring, 2004; Yuan & Bauer, 2007). It is well understood that green vegetation provides cooling effects in cities (Weng et al., 2004; Yuan & Bauer, 2007), and

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that impervious surface area (ISA) increases surface temperatures (Essa, van der Kwast, Verbeiren, & Batelaan, 2013; Mallick, Rahman, & Singh, 2013; Yuan & Bauer, 2007). The urban ISA is any nonporous land cover that prevents water from infiltrating into sub-surface layers, including buildings, roads, parking lots, sidewalks, driveways, and other built surfaces (Yang, Huang, Homer, Wylie, & Coan, 2003). Although early studies reported that percent distribution of ISA has a strong positive relationship with LST, individual effects of buildings and paved surfaces on LST was not well-investigated because these studies rely on medium spatial resolution images, such as Landsat and the Moderate Resolution Imaging Spectroradiometer (MODIS) (Chen, Zhao, Li, & Yin, 2006; Lazzarini, Marpu, & Ghedira, 2013; Yuan & Bauer, 2007), which do not have the capability to capture detailed land cover features (e.g., trees, individual buildings) in highly heterogeneous city environments. In contrast, the availability of very high resolution images, such as Quickbird and IKONOS, permits identification of more detailed land cover classes (e.g., trees, grass, buildings, and paved surfaces), and examination of their individual effects upon LST at finer spatial scales. For example, Myint et al. (2013) used a Quickbird image to discriminate detailed urban land use classes, and discovered that buildings do not contribute to the UHI effect in Phoenix — a desert city, but paved surfaces increase both daytime and nighttime LST. The study by Myint et al. (2013) demonstrated the potential of using very high spatial resolution imagery to reveal relationships between specific types of land cover and LST.

Very high resolution imagery also opens the possibility to investigate impacts of landscape configuration/structure upon the UHI (Cao, Onishi, Chen, & Imura, 2010; Connors, Galletti, & Chow, 2013; Li et al., 2011; Liu & Weng, 2008; Maimaitiyiming et al., 2014; Zhou, Huang, & Cadenasso, 2011). Landscape configuration/structure measures the spatial characteristics or arrangement of land cover parcels. These studies found that sizes, shapes, and segmentation of land cover parcels have influences on LST using landscape metrics derived from the FRAGSTATS software (Connors et al., 2013; Hart & Sailor, 2009; Li et al., 2011; Liu & Weng, 2008). However, these landscape metrics cannot fully represent the clustered and dispersed patterns of each land cover category, because they are calculated based upon discrete land cover parcels and ignore all other variation (Fan & Myint, 2014; McGarigal & Cushman, 2005). For example, patch density, one of the most popular FRAGSTATS metrics, is widely used to represent a number of patches per unit area. However, it cannot provide any information about the sizes and spatial distribution of patches. Thus, alternative methodologies that have the ability to depict and analyze both locational and attribute information of land cover features are required to effectively measure landscape configuration. Spatial autocorrelation indices, e.g., local Moran's *I* and Getis-Ord *Gi*, can simultaneously deal with differences in location and attribute values (Goodchild, 1986). The Getis-Ord *Gi* has been recently utilized to examine the role of spatial patterns of green vegetation on air temperature (Myint, 2012). Zhou et al. (2011) highlighted the importance of controlling for effects of land cover composition when evaluating effects of configuration of land cover features on LST. Although Zhou et al. (2011) adjusted the effects of land cover composition on LST using multiple linear regressions when they examined the relationships between configuration variables and LST, the quantitative relationships between configuration variables and LST under controlled environments with similar compositions of land cover types has not yet been studied.

Given the above background, this study aims to: examine effects of composition and spatial pattern (cluster or disperse) of anthropogenic land cover features (i.e., buildings and paved surfaces) on LST, and quantify effects of spatial pattern of anthropogenic land cover features on LST by minimizing effects of land cover composition on LST. Anthropogenic land cover is any land cover that is caused by human land use. In this context, anthropogenic land cover features are those typically referred to as buildings and paved surfaces. Results of this study will provide better understanding of the impacts of spatial patterns of anthropogenic land cover types on LST and provide insights for UHI mitigation.

2. Study area

The city of Phoenix is the capital of the state of Arizona with an estimated population of approximately 1.5 million (U.S. Census Bureau, 2012), ranking as the sixth most populous city in the United States. Our study area is located in central Phoenix, encompassing 178 km^2 areas (Fig. 1). The city has a subtropical desert climate with extremely hot summers and mild winters. Mean high temperature exceeds 38 °C throughout summer, making Phoenix the hottest city in the United States. The city has an average annual precipitation of 203 mm (ADWR, 2012). Precipitation follows a bimodal seasonal pattern with most rainfall occurs from December to March when winter storms move inland to Arizona, and from July to September during the monsoon season. The study area has a diverse urban land use and land cover classes, including commercial, industrial, and residential buildings, grassland, unmanaged soils, desert landscape, and open water.

3. Materials and methods

3.1. Land cover and land surface temperature data

Urban land cover classes were derived from a Quickbird image acquired on May 24, 2007 using an object-oriented classification approach (Myint, Gober, Brazel, Grossman-Clarke, & Weng, 2011). The Quickbird image has a spatial resolution of 2.4 m. Land cover categories include trees, grass, buildings, unmanaged soil, swimming pools, lakes and ponds, and paved surfaces (i.e., roads, parking lots, and sidewalks) (Fig. 1). The Quickbird image was first segmented into objects using Definients Developer 7.0. The object-oriented classification was then conducted using membership function and nearest neighbor classifier (Myint et al., 2011). Detailed classification procedures are demonstrated in Myint et al. (2011). A total of 500 points was sampled using a stratified random sampling approach with a minimum sample size of 50 per class for accuracy assessment. Table 1 lists classification accuracies for each land cover type. Overall accuracy of the classification map achieves 90.4%, with user's accuracies of 91.2% for buildings and 98.8% for paved surfaces (Myint et al., 2011; Table 1).

We used two advanced spaceborne thermal emission and reflection radiometer (ASTER) surface kinetic temperature images to map summer LST: one was acquired during daytime on July 6, 2005; the other was acquired at nighttime on August 27, 2005. The ASTER data has an absolute accuracy less than 1.5 K according to the product description (JPL, 2001). The surface kinetic temperature data were converted to surface temperature as degrees Celsius, providing land surface temperature data at 90 m spatial resolution. The land cover map and ASTER surface temperature image were co-registered—root mean squared errors of the image co-registration are 0.67 m for daytime ASTER data, and 0.58 m for nighttime ASTER data.

3.2. Composition and spatial pattern of anthropogenic land cover features

The Quickbird land cover map was resampled to 3 m spatial resolution. We then applied a 30 by 30 pixel window to the 3-m land cover map to calculate the composition/fraction of each land cover at 90 m spatial resolution.

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