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Exploring the effect of neighboring land cover pattern on land surface temperature of central building objects

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ABSTRACT

Increased temperatures in urban landscapes bring about a variety of problems and exacerbating thermal discomfort. Many studies have focused on detecting the effects of land cover patterns, including composition and configuration, on land surface temperature (LST) using remote sensing images. This study focused on distinct land cover feature, buildings, in center of Beijing, China, exploring the relationship between the LST of central building objects and land cover patterns in their neighboring areas. Classifying buildings into three groups (low-rise, mid-rise, and high-rise) allowed the effects of neighboring land cover patterns on building LST to be analyzed independently. We found that the composition of land cover features has a stronger impact on low-rise building LST than mid-rise and high-rise building LST. Moreover, low-rise building LST is highly related to the composition of neighboring vegetation and pavement. This relationship is limited for mid-rise buildings and high-rise buildings. Finally, LST can be mitigated not only by balancing the amount of vegetation and buildings, but, for low-rise buildings, can also be mitigated by optimizing their spatial configuration. This study enhances our understanding of the degree to which LST of different height buildings are affected by neighboring land cover patterns. In addition, important insights can be provided to urban planners on how to mitigate the impact of urbanization on UHI through urban design and vegetation management.

1. Introduction

Beijing serves as the center of Chinese policy and culture. Its population increased from 13.57 million in 2000 to 19.62 million in 2010 [1,2]. During the same period, the built environment increased from 488 to 1350 square kilometers [1,2]. This urban-based land conversion replaced soil and vegetation with impervious surfaces and urban structures such as buildings of various heights and densities [3,4]. These changes, in turn, have led to the formation of an urban heat island (UHI), resulting in the urban areas being warmer than surrounding non-urban areas [4].

Increased temperatures bring about a variety of problems, i.e., increasing electricity consumption [5] and exacerbating thermal discomfort [6]. Buildings are significant users of energy and materials and the closest urban structures to the public. Excess heat can also have detrimental effects on human health [7]. Thus, mitigating temperatures in areas can potentially reduce energy use and save money by reducing the demands for air conditioning. It can also improve urban thermal climate overall and lessen human health impacts.

It is widely accepted that loss in vegetation cover is an important factor causing UHI in urban areas [8]. Previous UHI studies have demonstrated the effects of the abundance and spatial arrangement of vegetation on LST [9–12]. Increasing vegetation, especially trees, provides more shade and facilitates energy exchange between vegetation and building areas, leading to a locally lower mean LST [11,13]. Roof greening has been demonstrated as an effective strategy for environmental quality improvement as well as land compensation [14].

In contrast, buildings have negative effects. Buildings affect LST not only through direct modification of surface characteristics, but also by changing the flow of organisms, material, and energy in a landscape [13,15]. Previous studies found buildings, as local features, have an important influence on UHI-intensity [16]. Moreover, buildings with different height and density have been shown to have different impacts on UHI [17]. Low-rise high-density models are highly correlated with UHI. High-rise housing, on the other

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hand, demonstrates positive effects on heat island mitigation as it releases more land at ground level for green space and wind corridors [18]. Moreover, tall buildings provide a large amount of shading, which influences the behavior of other land cover features [17]. Thus, the effect of neighboring land cover pattern on LST needs be analyzed separately with a focus on buildings with different height and density.

Previous research has primarily focused on land cover patches, examining the effect of their size, shape and spatial arrangements [19–21]. LST in many of these studies is defined as pixel-based areas in thermal image data or specific object areas with several types of land cover features mixed in. Few studies have attained object-based LST to focus on the LST of a distinct building feature or explored the relationship between LST of a central patch and land cover patterns in the neighboring areas.

This study focuses on surface temperatures for building patches specifically. The objectives are to (1) attain LST for each building patch; (2) examine the effect of surrounding land cover composition on the LST of these building patches; and (3) investigate whether the building configuration as well as the composition of vegetation significantly affects LST. The results from this study will enhance our understanding of the degree to which LST of different building heights are affected by neighboring land cover patterns. In addition, important insights can be provided to urban planners on how to mitigate the impact of urbanization on UHI through urban design and vegetation management.

2. Method

2.1. Study site

Beijing, the capital of China, has a monsoon-influenced humid climate with four distinct seasons. Since the late 80s, Beijing has experienced rapid urbanization and city expansion, resulting in significant UHI effects. Beijing's development follows a ring-shaped pattern, and our study area (Fig. 1) covers the northwest quarter of the region inside the forth ring road with an area of 74.332 km^2. Land cover features are typical of urban environments, including commercial and residential buildings with different heights; impervious surfaces such as asphalt roadways and sidewalks; vegetation cover consisting of trees and grass; and water bodies consisting of an approximately 2 km^2 lake and some artificial rivers.

2.2. Data

Remotely sensed LST data records the radiative energy emitted from ground surfaces such as building, pavement, vegetation, bare land, and water [4,22]. Some studies show that by replacing darker materials with high-albedo surfaces, buildings and roads can be effectively cooled [3]. Land cover patterns in a building's neighboring areas may also influence the temperature of the building and its immediate neighborhood. However, this has not been studied extensively using remote sensing data.

2.2.1. Measures of the composition and configuration of land cover features

A variety of metrics has been developed to measure and describe the composition and configuration of land cover features [23,24]. These metrics, reflecting a number of prime spatial pattern characteristics of land cover features, include composition metrics that measure the percent cover of each land cover feature (PLAND); and configuration metrics [23,24] that include fragmentation indices such as largest patch index (LPI) and edge density (ED); patch size indices such as the mean and standard deviation of patch size (MPS, PSSD); shape indices such as area weighted mean patch fractal dimensions (AWMPFD); proximity index, which is mean proximity index (MPI); and adjacency matrices that determine an interspersion juxtaposition index (IJI) (Table 1). The percent cover and the seven configuration metrics were used as contributing variables in the statistical analysis to detect the relationship between LST of different groups of building patches and the cover pattern of green vegetation in their neighborhood. In order to describe and measure the vegetation's spatial distribution, we calculate configuration metrics at the class level.

2.2.2. Land cover classification

QuickBird images acquired in the summer of 2004 were used to obtain detailed land cover information in the study area. A patch-based layer of different land cover types in vector format was created using object-based image analysis (OBIA). The classification procedure contains three steps: image segmentation, feature determination, and object classification. At first, five land cover features were included in the classification map: (1) buildings, (2) pavements (PAV), (3) vegetation (VEG), (4) water (WAT), and (5) shade [26].

Buildings with similar heights tend to have similar functions and analogous roofing materials; therefore, grouping may eliminate the impact of the buildings' roofs on temperature. This is especially true for buildings concentrated in the small areas such as those used in this study. A one-way ANOVA was used to detect whether the height of building has a significant effect on LST. The Leneve's test showed that variances are unequal because the test statistic's significance is smaller than 0.05. Hence, Tamhane's method is chosen as the post hoc test. The results show that the dependent variable (the building LST) is significantly different among different groups of buildings (Table 2).

As a result of these findings, we reclassified the buildings to specific subclasses with different heights. Instead of introducing other accurate elevation data, the percentage of shade area within 100 m buffer ring for each building patch in this image is utilized as a parameter to classify which subclasses each buildings should be in. The buildings were divided into three groups: (1) low-rise buildings (1–3 stories) with neighboring shade ratios less than 0.01% (LRB) (Fig. 2 (a)), (2) mid-rise buildings (about 4–7 stories) with neighboring shade ratios between 0.01% and 0.05% (MRB) (Fig. 2 (b), and (3) high-rise buildings (no less than 8 stories) with neighboring shade ratios more than 0.05% (HRB) (Fig. 2 (c). We determined shade for other land cover features using manual interpretation as shade is not a real land cover feature. Testing the threshold value of the shade ratio repeatedly, together with visual interpretation, ensured the quality of the reclassified buildings considering the 0.61 m-resolution of QuickBird images.

Six land cover features were derived—low-rise buildings (LRB), mid-rise buildings (MRB), high-rise buildings (HRB), pavements (PAV), vegetation (VEG), and water (WAT). Fig. 3 shows the final classification map. The overall accuracy of the classification was 90.8%, with producer's accuracies ranging from 81.0% to 97.3% and user's accuracies from 74.3% to 100.0% (Table 3). Most misclassifications were ascribed to low-rise buildings and pavement. The reason being that some low-rise buildings with little shade, pavement-like roof surfaces (i.e., asphalt tiles), and slender structure are easily misclassified as pavement.

2.2.3. Land surface temperature

LST data were extracted from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) images acquired on August 31, 2004. ASTER, an advanced multispectral imager on board the NASA's EOS-Terra satellite, has a wide spectral region of visible to near infrared (VNIR, 15-m spatial resolution), shortwave infrared bands (SWIR, 30-m spatial resolution), and thermal