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Comparison of impervious surface area and normalized difference vegetation index as indicators of surface urban heat island effects in Landsat imagery

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Abstract

This paper compares the normalized difference vegetation index (NDVI) and percent impervious surface as indicators of surface urban heat island effects in Landsat imagery by investigating the relationships between the land surface temperature (LST), percent impervious surface area (%ISA), and the NDVI. Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) data were used to estimate the LST from four different seasons for the Twin Cities, Minnesota, metropolitan area. A map of percent impervious surface with a standard error of 7.95% was generated using a normalized spectral mixture analysis of July 2002 Landsat TM imagery. Our analysis indicates there is a strong linear relationship between LST and percent impervious surface for all seasons, whereas the relationship between LST and NDVI is much less strong and varies by season. This result suggests percent impervious surface provides a complementary metric to the traditionally applied NDVI for analyzing LST quantitatively over the seasons for surface urban heat island studies using thermal infrared remote sensing in an urbanized environment.

Keywords: Impervious surface area; Land surface temperature; Normalized difference vegetation index; Spectral mixture analysis; Surface urban heat island; Landsat TM/ETM+

1. Introduction

The urban heat island (UHI) refers to the phenomenon of higher atmospheric and surface temperatures occurring in urban areas than in the surrounding rural areas due to urbanization (Voogt & Oke, 2003). It is characterized by a large expanse of non-evaporating impervious materials covering a majority of urban areas with a consequent increase in sensible heat flux at the expense of latent heat flux (Oke, 1982; Owen et al., 1998). UHI effects are exacerbated by the anthropogenic heat generated by traffic, industry and domestic buildings, impacting the local climate through the city's compact mass of buildings that affect exchange of energy and levels of conductivity. The higher temperatures in urban heat islands increase air conditioning demands, raise pollution levels, and may modify precipitation patterns. As a result, the magnitude and pattern of UHI effects have been major concerns of many urban climatology studies.

Heat islands can be characterized for different layers of the urban atmosphere and for various surfaces and divided into three categories: canopy layer heat island (CLHI), boundary layer heat island (BLHI), and surface urban heat island (SUHI). The urban canopy layer extends upwards from the surface to approximately mean building height, whereas the urban boundary layer is located above the canopy layer (Voogt & Oke, 2003). The CLHI and the BLHI are atmospheric heat islands since they denote a warming of the urban atmosphere, whereas the SUHI refers to the relative warmth of urban surfaces compared to surrounding rural areas. It is known that atmospheric UHIs are larger at night while surface UHIs are larger during the day (Roth et al, 1989). While atmospheric heat islands are normally measured by in situ sensors of air temperature via weather station networks, the surface UHI is typically characterized as land surface temperature (LST) through the use of airborne or satellite thermal infrared remote sensing, which provides a synoptic and uniform means of

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studying SUHI effects at regional scales. Satellite-measured LST has been utilized in various heat-balance, climate modeling, and global-change studies since it is determined by the effective radiating temperature of the Earth's surface, which controls surface heat and water exchange with the atmosphere. Voogt and Oke (2003) suggested three major applications of thermal remote sensing to the study of urban climates. Two of them focus on examining relations either between spatial structure of urban thermal patterns and urban surface characteristics or between atmospheric and surface heat islands; the third is centered on studying urban surface energy balances by coupling urban climate models with remotely sensed data. Our study addresses the first application area.

In earlier thermal remote sensing studies, much emphasis has been placed on using the normalized difference vegetation index (NDVI) as the major indicator of urban climate. For example, Gallo et al. (1993) assessed the influence of the urban environment on observed minimum air temperatures by analyzing urban–rural differences for NDVI and surface temperatures. Lo et al. (1997) studied changes in the thermal responses of urban land cover types between day and night and examined the relation between land cover radiance and vegetation amount using NDVI derived from Advanced Thermal and Land Applications Sensor (ATLAS) data. Gallo and Owen (1999) evaluated seasonal trends in temperature and NDVI and found that differences in NDVI and satellite-based surface temperature accounted for 40% of the variation in urban–rural temperature differences. The NDVI–temperature relationship has also been utilized in various studies to derive or evaluate two variables — fractional vegetation cover and surface soil water content for climate modeling (Carlson et al., 1995a; Gillies & Carlson, 1995; Gillies et al., 1997; Goward et al., 2002).

Higher NDVI values typically indicate a larger fraction of vegetation in a pixel. The amount of vegetation determines

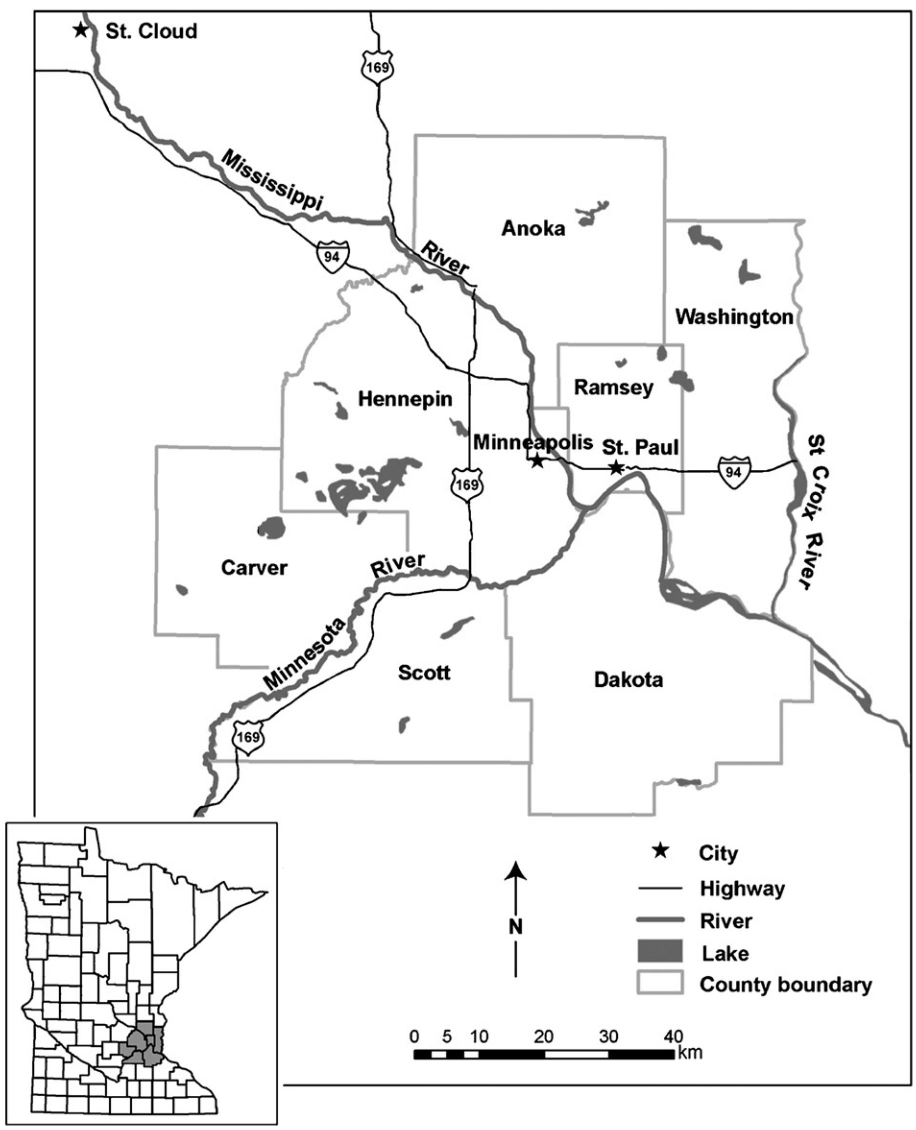

Fig. 1. Seven-county Twin Cities Metropolitan Area (TCMA) of Minnesota.