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Spatial and temporal variations of urban heat island effect and the effect of percentage impervious surface area and elevation on land surface temperature: Study of Chandigarh city, India

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ABSTRACT

Significant surface urban heat island (SUHI) has been observed in the Chandigarh study area from the analysis of five years land surface temperature (LST) data from 2009 to 2013. UHI intensity over the study area varies with seasons. Average annual UHI intensity from 2009 to 2013 varies from 4.98 K to 5.43 K and overall average UHI intensity has been observed to be 5.2 K. The maximum value of UHI_{index} has been found to be 0.93. Pixels with average value of UHI_{index} more than 0.90 have been considered as hot spots (HS). The relationship of LST between percent impervious surface area (%ISA) and elevation has been investigated in the present study. Parameter like %ISA which represents the extent of urbanization has been used for the UHI analysis and its relationship with LST has been found to be season independent. Positive relationship has been found between LST and %ISA with a consistent rising trend. In the mean LST and %ISA relationship, it has been observed that the coefficient of correlation of winter season is 0.81 which is slightly higher compared to monsoon and summer seasons. Normally the temperature falls with increase in altitude. But in this study, as the elevation increases, rising trend of LST can be observed. Negative relationship between LST and Elevation scatterplots has been observed in high altitude areas during monsoon season compared to summer and winter seasons. Besides other factors elevation also plays a significant role in LST dynamics and spatial distribution of LST.

1. Introduction

Urbanization, one of the main factors causing unnatural changes in climate patterns around the globe, is infecting our world drastically. All cities of the world have witnessed rapid urbanization, which causes conversion of natural land surfaces having predominantly vegetation and pervious areas into built-up and impervious areas. This impervious area is mainly contributed by use of different materials like concrete, bricks, tiles, asphalt, bitumen etc. for buildings, roads and parking lots (Landsberg, 1981). Radiative, thermal, moisture, roughness and emission properties of the surface and the atmosphere have drastically changed due to the introduction of new surface materials coupled with emission of heat, moisture and pollutants (Roth, 2002). Surface and atmospheric modifications due to urbanization generally lead to a modified thermal environment that is warmer than the surrounding rural areas, particularly at night. This phenomenon is referred as UHI effect (Voogt & Oke, 2003). Land use/land cover (LU LC) changes have been reported to be one of the main drivers of environmental change, while climate change and climate variability may influence LU preferences differently in various parts of the world (Brunsell, 2006). Satellite imageries have become an effective tool for UHI studies as the satellite data is more uniform, larger and regular, as compared to ground sensors (Hung, Uchihama, Ochi, & Yasuoka, 2006). Land surface temperature (LST) is one of the primary key parameters controlling the physical, chemical and biological processes of the Earth and is an important factor for study of urban climate (Pu, Gong, Michishita, & Sasagawa, 2006). Remote sensing data provides a practical approach for the retrieval of LST on wide spatial and temporal scales. Planck's law is used for calculating brightness temperature from atmospheric radiances obtained from thermal infrared sensors (Dash, Gottsche, Olesen, & Fischer, 2003). The brightness temperature is converted into LST using ground surface emissivity which accounts for vegetation density, roughness

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Nomenclature

UHI	Urban heat island
LST	Land surface temperature
MODIS	Moderate-resolution imaging spectroradiometer
ASTER	Advanced spaceborne thermal emission and reflection radiometer
%ISA	Percent impervious surface area
HS	Hot spots
CBD	Central business district
LSMA	Linear spectral mixture analysis
DEM	Digital elevation model

and thermal properties of ground surface and water content in the soil (Friedl, 2002). LST is generally defined as the skin temperature of the surface which refers to soil surface temperature for bare soil and canopy surface temperature of vegetation for densely vegetated ground. For sparse vegetated ground, LST is determined by the temperature of the vegetation canopy, vegetation body and soil surface (Qin & Karnieli, 1999). LST, derived from remote sensing data recorded through sensors on-board satellites, has been utilized in numerous heat-balance, climate modelling and global-change monitoring studies (Bhattacharya, Mallick, Patel, & Parihar, 2010; Fall et al., 2010; Lakshmi, Hong, Small, & Chen, 2011). UHI studies conducted using LST data from satellite observations are referred as surface urban heat island (SUHI) studies and many SUHI studies have been conducted using thermal remote sensing data from satellites (Aniello, Morgan, Busbey, & Newland, 1995; Dousset & Gourmelon, 2003; Kourtidis et al., 2015; Kloka et al., 2012; Li et al., 2016; Streutker, 2002; Roth, Oke, & Emery, 1989; Shen, Huang, Zhang, Wu, & Zeng, 2016).

The main cause of SUHI is alteration of land surfaces through urban development with the use of materials that effectively retain heat. On the other hand, urbanization negatively affects the environment due to pollution thus modifying the physical and chemical properties of the atmosphere, and the soil surface (Kaya et al., 2012). Materials such as bitumen, asphalt, brick, concrete etc. absorb and store solar radiations during the day and release it gradually at night. Hence, SUHI intensity is observed to be stronger at night as compared to day time. Urban geometry is also one of the main factors causing UHI effect. Urban canyons are normally represented by narrow streets and wind speed is reduced by tall buildings which cause heat storage by increase in reflective surfaces (Abutaleb et al., 2015). It has been suggested that simple methods have to be implemented to calculate the UHI intensity within urban areas, as a function of time, climatic conditions and structural attributes (Arnfield, 2003).

Peng et al. (2012) have observed significant higher SUHI in the day than at night and they have attributed the spatial variability to the urban–suburban differences in vegetation activity during the daytime and in albedo and anthropogenic heat releases during night. Zhou, Zhao, Liu, Zhang, and Zhu, (2014) have studied the diurnal and seasonal SUHI intensity in China's 32 major cities and have calculated urban–suburban temperature difference in the form of surface urban heat island intensity (SUHII). They have concluded that SUHII varies greatly with season and it strongly depends on the geographic location of the place and research period. UHI intensity has been shown to be influenced by intrinsic nature of the city and other external parameters of the city such as size of the city, built-up density, LU distribution etc. (Kalnay & Cai, 2003; Kim & Baik, 2005; Magee, Curtis, & Wendler, 1999; Montavez, Rodriguez, & Jimenez, 2000; Oke, 1982).

Correlation of LST with various parameters representing surface properties of the ground has been the core of many studies on UHI effect. The correlation of LST between normalized difference vegetation index (NDVI) and emissivity has been found to be negative, whereas a positive correlation has been observed between normalized difference built-up index (NDBI), albedo and temperature (Kikon, Singh, Singh, & Vyas, 2016). Built-up land has been suggested as the most significant contributor to the increase in surface temperatures. The contribution of cropland and forest towards increase in LST varies distinctly between day time and night time due to differences in their thermal inertias (Qiao, Tian, & Xiao, 2013). The spatial pattern of impervious surfaces has been related to the urban development and it has consequently been related to the regional eco-environmental changes (Li, Ouyang, Zhou, & Chen, 2011).

The correlation between LST and vegetation has been observed to depend on the season of the year and strong negative correlation between LST and NDVI has been reported in the warm months (Yuan & Bauer, 2007). Liang and Weng (2008) have indicated that LST shows negative correlation with water and vegetation and strong positive correlation with buildings and roads. The variation in surface temperature indicates that the climatic variation is mostly characterised by vegetation cover on the Earth's surface rather than a rapid climate change attributable to climate sources in the study area (Parida et al., 2008). Percent impervious surface area (%ISA) has been found to be an accurate indicator of SUHI effects with strong linear relationship between LST and %ISA for different seasons (Rong-bo et al., 2007; Yuan & Bauer, 2007). Positive exponential correlation exists between impervious surface and LST, while vegetation and water show inverse relationship with LST. Regional LST change has been mainly contributed by impervious surfaces and the contribution can be up to six times greater than the combined contribution by water and vegetation. LST can be reduced up to 2.5 °C or 2.9 °C for each decrement of 10% impervious surface cover with additional 10% vegetation or water space (Xu, Lin, & Tang, 2012). Zhang, Odeh, and Han, (2009), utilizing data from Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) imageries, have indicated strong positive correlation of LST with %ISA and NDBI whereas the correlations between NDVI and LST have been found to be weak. Their study suggests that %ISA combined with LST and NDBI can quantitatively explain the spatial distribution and seasonal variations of urban thermal patterns and associated LU LC conditions. Urban LC change has been found to be statistically significant when related to a decrease in normalized values of fractional vegetation cover (FVC) and increase in normalized values of surface radiant temperature (Owen, Carlson, & Gillies, 1998). Areas with high built-up density have highest temperatures which is related to the thermal properties of the existing structures and the street geometry (Ao & Ngo, 2000). Change in LST due to change in elevation of different areas has been found to be different from environmental lapse rate. When UHI studies are conducted for large areas where the ground terrain is variable, the effect of change in LST due to change in elevation shall also be considered. Spatial variation of vegetation indices is not only subject to the influence of vegetation amount, but also to topography, slope, aspect, solar radiation availability, and other factors (Walsh, Moody, Allen, & Brown, 1997). In remote sensing image of the mountainous regions, due to the effect of the ground slope, high density of vegetation is recorded over such regions. Hence ground terrain and topography of a particular area is an important factor for UHI studies.

The present study has been carried out to analyze the UHI effect over Chandigarh city, India. The objective of the research is to find the UHI intensity over the city for different seasons. The effect of %ISA which can be used as a parameter to express urbanization over LST has been studied. The effect of change is elevation of an area over LST has also been analyzed.