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Characterization of thermal environment over heterogeneous surface of National Capital Region (NCR), India using LANDSAT-8 sensor for regional planning studies

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ABSTRACT

Land surface temperature (LST) is an essential indicator of the Earth's surface energy budget. It is essential for urban micro-climate change studies and acts as a controlling variable in climatic models. The present study, LST retrieves with the improved mono-window algorithm from the Landsat-8 Thermal Infrared Sensor Band 10. The proportion of vegetation cover coupled with Normalized Difference Vegetation Index (NDVI) used for the estimation of emissivity. The derived emissivity and surface temperature over different ground features have compared with field observation as well as those in the literature and found in an accepted range (error of around 1–2%). Herein, results show that the spatial distribution of surface temperature was significantly affected by landscape characteristics. The built-up and commercial/industrial areas display higher surface temperature in comparison with surrounding other vegetated lands. Whereas, the cooling effect towards the surrounding urban built-up area are found increasing in the vegetated area, and inside the green zones. A strong correlation is observed between the LST with NDVI over different land cover and land use (LCLU) classes. The Geoinformation technique provides a practical-based theoretical model of the land characterization of an urban thermal environment which assists in regional planning and decision-making process.

1. Introduction

With the rapid urbanization and widespread urban sprawl have depleted vegetated cover and have increased vulnerability to micro-climate change in urban areas. It became increasingly severe problems in the semi-arid climatic zone (Koppen Geiger: BSh) specifically National Capital Region (NCR), India (Mallick et al., 2008; Yogesh et al., 2009; Suzanchi and Ravinder, 2011; Mallick et al., 2013). In hot semi-arid climates the NCR experiences, long summer, hot and dry climate. The neighbourhood micro-climate at the micro-scale closely relates to people's daily life (Roth, 2002). It is thus essential and necessary to study the urban climate and the neighbourhood microclimate in the hot semi-arid region for improving environmental quality, reducing building energy consumption and mitigating urban thermal environment for better quality of life.

Land surface temperature (LST) can be an essential source of information about the energy budget and climate, plays an essential role in many environmental and biophysical processes (Dousset and Gourmelon, 2003; Weng et al., 2004; Mallick et al., 2008). Previous studies have evaluated the relative temperature of urban settings by measuring the air temperature, using site-based measurement stations. Several researchers observing the temperature using infrared thermal sensors mounted on a vehicle, along with specified route (Yamashita et al., 1996). This technique is time-consuming and expensive and increases the problems in spatial

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analysis and interpolation. Satellite-based remote sensing techniques could be an enhanced alternative to retrieve the LST and other biophysical parameters. In the remote sensing technique, optical and thermal infrared (TIR) sensors have been used to acquire quantitative information on biophysical parameters and surface temperature respectively across the landscape.

Urbanization is creating massive transformation in land cover thereby modify the sensible and latent heat fluxes of the surface. Concrete Impervious surface areas have higher sensible heat in respect to vegetated areas, resulting in higher temperatures of urban built-up surfaces on the contrary to vegetated lands (Liu et al., 2012; Rahman et al., 2011). With this geographic phenomenon of thermal environment, other anthropogenic activities such as increased pollutant emission (Ali and Nitivattananon, 2012), population density (Mallick and Rahman, 2012) and others change the environment at local to regional scales (Grimm et al., 2008).

Due to their relevance to regional climate, quality life, urban air quality, land cover/land use (LCLU) change and carbon emission urban environment studied extensively worldwide over the last two decades viz. Shanghai (Chow, 1992), Tokya (Saitoh et al., 1996), Mexico City (Jauregui, 1997), Houston (Streutker, 2003), Indianapolis (Lu and Weng, 2006), Salt lake valley (Gluch et al., 2006), London (Jones and Lister, 2009), Tabriz (Amiri et al., 2009), Greater Athens (Keramitsoglou et al., 2011), Lahore (Ali and Nitivattananon, 2012), Dhaka (Molla et al., 2012), Wisconsin (Deng and Wu, 2013), Faislabad (Ali et al., 2012; Shabana et al., 2015) and Bangkok (Ali et al., 2017). In the Indian scenario, research on the urban thermal environment given more emphasis during the last decade (Mallick et al., 2008; Pandey et al., 2012; Chakraborty et al., 2013; Mallick et al., 2013; Mathew et al., 2016). However, the researchers investigated urban environment and Normalized Difference Vegetation Index (NDVI) relationship for major cities around the developed world. There is a gap of the research related to the large regions that comprise many cities of India. Problem statement concerning to land surface emissivity, LST and NDVI are explored by Mallick et al., 2008, Kant et al., 2009, Mallick et al., 2012, Sharma and Joshi, 2013a, 2013b for Delhi, while an urban thermal environment for NCR, India as a whole is still unexplored. Moreover, the rapid expansion of urbanization in NCR, India (Sharma and Joshi, 2016) during the last few decades has driven researchers to examine the urban thermal environment effects from an entirely new perspective in recent years.

In this study, LST retrieves with the improved mono-window algorithm from the Landsat-8 Thermal Infrared Sensor Band 10 and the proportion of vegetation cover coupled with Normalized Difference Vegetation Index (NDVI) used for the estimation of land surface emissivity (LSE) of NCR, India. The various studies of the ground emissivity databases (Salisbury and Daria, 1992) opted from laboratory measurements, and it represents the site-observation rather than the per-pixel spatial observation. Hence, the surface emissivity parameter per pixel needs to be derived from satellite pixel scale (30 × 30 m of Landsat-8 in this case) to have an accurate estimation of LST and assessment of other biophysical parameters. The study includes the assessment of the spatial variations of LST over different LCLU, relationship with vegetation cover. It also investigates the relationship between urban development, the ground-based measurements, satellite-derived land surface temperatures. The Geoinformation technique provides a practical-based theoretical model of the land characterization of an urban thermal environment which assists in regional planning and decision-making process.

2. Database and methodology

2.1. Study area: NCR, India

The National Capital Region (NCR) in India is a metropolitan area which consists of National Capital Territory (NCT) of Delhi, as well as urban areas surrounding it in neighbouring states of Haryana, Uttar Pradesh, and Rajasthan. National Capital Region (NCR) having a total area of 46,208 km^2 extending over 18 districts of Uttar Pradesh, Haryana, and Rajasthan and NCT of Delhi and constitutes about 1.60% of the country's land area.

In the NCR region, Delhi, the capital city of India, is the second most populated megacity in the world with nearly 17 million people with an area of 1483 km^2. Population in Delhi has increased from 1.7 million in 1951 to 13 million in 2001, finally crossing the mark of 16.7 million in 2011 (Census of India, 2011), as one of the high spread of suburban area in history (United Nations, 2012). This unprecedented growth has attracted a broad community of scientists and researchers to analyse the complex LCLU of Delhi (Sokhi et al., 1989; Punia et al., 2011; Wentz Elizabeth et al., 2008; Rahman et al., 2011; Mallick et al., 2013). In 1991, the urban core of Delhi was expanded to nearby interstate city areas such as Ghaziabad, Meerut, and Noida of Uttar Pradesh and Faridabad and Gurgaon of Haryana forming the National Capital Region (Fig. 1). Following this elevated status, this region has experienced rapid spatial changes in its landscape patterns. These changes, whether conversion of agricultural land to industry and civic facilities or sparse built-up areas to dense built-up areas have impacted the residential patterns, agricultural practices, urban thermal environment and urban forest distribution in the city. NCR, Delhi is characterized by highly complex land use practices with impervious concrete surfaces dominating the commercial, industrial as well as residential areas; and patches of forests at the heart of the city, in the north and the south. Peri-urban areas and banks of Yamuna River are predominantly covered with agricultural lands. Such high heterogeneity of land use provides high dynamism of land transformations over both long-term as well as short-term scales. The region has a tropical steppe climate. The general prevalence of continental air leads to relatively dry conditions with sweltering summers. Mean monthly temperatures range from 14 °C in January (min. 3 °C) to 35 °C in June (max. 47 °C). The NCR, Delhi experiences five significant seasons; winter (Nov–Feb), spring (Feb–Mar), summer (Apr–Jun), Monsoon (Jul–Sep), and Post-monsoon (Oct–early Nov).

2.2. Database

Landsat-8 is one of the most helpful satellite data for environmental and ecological studies. There are two new sensors on Landsat-