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Research Paper

Evaluating urban heat island in the critical local climate zones of an Indian city

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ABSTRACT

The rise in global temperature and rapid pace of urbanisation is fuelling the need to understand cities and its climate implication. Measuring urban heat island (UHI) have significant contribution in understanding this interrelationship. This paper aims at measuring canopy layer heat island (CLHI) in a compact city of Nagpur, India using local climate zone (LCZ) classification. It also accesses the inter-LCZ temperature difference within the city and identifies critical areas that require intervention to curb heat island. The methodology describes LCZs mapping, data collection technique using fixed station points and mobile traverse survey conducted during the month of December 2015 and February 2016 of winter season. The paper adopts rigorous data filtering technique to avoid the errors in reporting UHI of cities having compact and heterogeneous built form like Nagpur. The study covers temperature buffer analysis, sensor lag determination, forecasting, outlier analysis and Pearson – correlation technique. It also examines the thermal anomaly in different LCZ with respect to cities average for identifying critical areas. The result shows that UHI intensity within built LCZ (IUHI), in winter season for Nagpur city, ranges from 1.76 to 4.09 °C. The compact low-rise LCZs present at the urban core were found to be warmer than other major LCZ present in the inner areas of the city. The study also reports thermal variation between traditional LCZs and the LCZs with subclasses. The study concludes with identification of critical LCZs in terms of IUHI and suggests the need for intervention.

1. Introduction

Rapid pace of urbanisation in developing countries is leading to modification of land cover, urban fabric and urban geometry. It is also increasing the rate of urban heat absorption (Chen, Chiu, Su, Wu, & Cheng, 2017) which in turn is affecting climate of the city (Eliasson, 2000). With changes in the urban form and function, cities are modifying the overlying climate (Mills, 2007). Studies show that urban areas play a significant role in tending climate change (Kalnay & Cai, 2003). Urban heat island effect (UHI) is widely studied to examine the city's contribution in rising temperature (e.g., Arnfield, 2003; Chow & Roth, 2006; Eliasson, 1996; Kim & Baik, 2005; Klysik & Fortuniak, 1999; Landsberg, 1981; Oke & Maxwell, 1975; Roth, 2007; Santamouris & Kolokotsa, 2016). UHI is defined as near surface air temperature difference between urban and it's surrounding rural areas (Oke, 1982). It can be classified into three types: i) canopy layer heat island (CLHI) ii) boundary layer heat island (BLHI) and iii) surface heat island (SHI) (Voogt and Oke, 2003). CLHI deals with the air temperature between ground surface and roof height of buildings. It provides an intrinsic representation of human and energy interactions postulating the resultant urban climate. Understanding CLHI would enable urban planners and decision makers to identify the UHI critical areas and propose suitable mitigation methods.

Majority of research work investigates UHI study using the thermal difference between urban-rural class, vegetation-built density and pervious-impervious fraction classes of land cover (Stewart, 2007, 2011). Urban interventions for mitigating UHI requires intrinsic land cover study, which considers major aspects of physical, geometrical and anthropogenic factors at the local scale. Based on these parameters, Stewart and Oke (2012) developed a land cover classification system called as Local Climate Zone (LCZ). LCZ classification has two categories of land cover—built and natural. It is further subdivided in 17 classes based on various geometrical and physical aspects (Stewart & Oke, 2012). Applicability of LCZ classification for different UHI study domains is well established by various researchers (Alexander & Mills, 2014; Alexander, Fealy, & Mills, 2016; Leconte, Bouyer, Claverie, & Pétrissans, 2015; Perera & Emmanuel, 2016; Stewart, Oke, & Krayenhoff, 2014; Savić, Milošević, Marković,

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Bajšanski, & Šećerov, 2016). Kochi (India), Delhi (India), Colombo (Sri Lanka) and Hong Kong are some of the tropical cities that have also evaluated UHI using LCZ framework (Perera & Emmanuel, 2016; Siu & Hart, 2013; Sharma, Hooyberghs, Lauwaet, & De Ridder, 2016; Thomas, Sherin, Ansar, & Zachariah, 2014).

This study aims at i) estimating the CLHI for the heterogeneous built city Nagpur, Maharashtra, India using the local climate zone classification and ii) identifying critical LCZs in terms of UHI for planning interventions.

2. Previous studies

UHI studies are gaining importance in the urban areas of tropical regions (Roth, 2007) and most of tropical cities are showing presence of heat islands throughout the year (Jonsson, 2004). This is also observed in several of Indian cities like Pune, Ahmedabad, Delhi, Mumbai and Chennai. Various methods like satellite based SHI study, station survey and mobile traverses are used to determine CLHI (Amirtham & Devadas, 2008; Grover & Singh, 2016; Joshi et al., 2015; Mohan et al., 2012; More, Kale, Kataria, Rane, & Deshpande, 2015; Rose, 2010; Roy, Singh, & Kumar, 2011).

Previous UHI study conducted by Katpatal et al. (2008) examined SHI and CLHI for Nagpur city. Katpatal et al. (2008) used Landsat 5 TM satellite imagery of 5th November and 21st December 2001 at 11:00 a.m. for SHI estimation and field study conducted on 21–23 December 2002 to estimate CLHI. His study examined six land cover classes depending on the vegetation to built land cover ratio and reported UHI of 1–2 °C between 100% built-up areas and 40–60% built-up areas. In another extensive research conducted in 2012, using station and traverse survey, CLHI of Nagpur ranged between 1.28 °C–3.62 °C (Kotharkar & Surawar, 2016). This was determined using seven land use and land cover (LULC) classes based on vegetation to built ratio. The air temperature investigations involved measurements using mobile survey. Mean nocturnal UHI during November (winter period) 2012 was 2.9 °C.

These studies indicate presence of UHI in Nagpur city, however, the associated LULC classes are only restricted to built and vegetation ratio. Major shortcoming of these classes is the negligence of important spatial characteristics, including height of roughness and type of building material used. UHI associated with merely six land cover types reduces the mitigation opportunities at urban planning level. Present study identifies these shortcomings and proposes a more detailed approach in addressing the UHI effect.

3. Methodology

This study uses LCZ classification for determining CLHI magnitude, which involves mapping of LCZ, collection of air temperature data through various surveys followed by the analysis of data using atmospheric stability classes, Pearson correlation method, outlier analysis and thermal anomaly study. The software tools used for the data assimilation, segregation and analysis included ArcGIS, MS Excel, Minitab, Hoboware and Holux GPS logger utility.

3.1. Nagpur city

City's size and morphology plays an important role in governing magnitude of heat island (Roth, 2012). Understanding the city of Nagpur was the preliminary step taken to identify procedure required for examining UHI. This included the study of topography, climate, population density, land use, land cover, urban setting and urban form.

3.1.1. Topography and climate

Nagpur is a tropical city that lies at the geographic centre of India. It is located at an altitude of 310.5 m above mean sea level, 21° 06′ N latitude and 79° 03′ E longitude as shown in Fig. 1. Its municipal region covers 225.08 km^2 area of land witha tropical wet and dry type of climate, Nagpur has the highest temperature record of 48 °C during summer and lowest of 6 °C during winter (Anon., 2012). Nagpur's climate is categorised under four seasons namely the summer, monsoon, post monsoon and winter (India Meteorological Department, 2011) with light and moderate winds throughout the year. Humidity is high (70–80%) during moonsoon but the air is generally dry during the rest of the season. Summer season is driest with relative humidity around 20% or less particularly in the afternoons (India Meteorological Department, 2011).

3.1.2. Demography and land use

Nagpur, classified as a Tier 2 city, is the third largest city in Maharashtra, an Indian State, it has a population of over 2.4 million and gross population density of 11,000 persons/sq km. Based on the present rate of population growth, it is predicted that in 2041 the population will be 2.5 times the population of 2011. 45% of the city's land cover is used for residential land cover, 41% for institutional use, 6% for commercial and industries use and the remaining 8% for gardens (CRISIL Risk and Infrastructure Solutions Limited, 2015).

3.1.3. Urban Form

Nagpur is a mono-centric city with major commercial areas in the centre and a few sub centres spread over the city (Kotharkar, Bahadure, & Sarda, 2014). Located at the center of the city, '*Sitabuldi*' is the oldest marketplace and central business district (CBD) of Nagpur city. The old area '*Mahal*' is situated beside the CBD and has a wide variety of built structures ranging from old residences made up of traditional building materials to the newly built concrete houses. Narrow roads existing from colonial times are patched repaired and redone to fit the current development pattern. This part of city, which forms the urban core, is both densely built and populated. Around this core is the inner city region that is well planned and developed as per developmental control regulations. The buildings of the medieval and colonial periods house government offices and institutions.

The city' is on the threshold of moving from a compact city to an urban sprawl as it continues to grow outwards. Low-rise development within the city and low floor space index (equivalent to one) are other reasons for driving the growth around the fringe areas. The city's airport lies to the Southwest and is responsible for attracting development in surrounding areas. Also, the villages in the vicinity are witnessing modern concrete construction, thereby transforming the urban fringe.

Nagpur city has more than 135 parks and open spaces spread across the neighbourhoods. The slums in Nagpur are fragmented and spread over different parts of the city and have a footprint of 17 sq km, which is 10% of the city area (CRISIL Risk and Infrastructure Solutions Limited, 2015).

3.2. LCZ mapping

Literature review was undertaken to study the various mapping techniques used to map LCZ in different cities and select the most suitable technique. The review showed that the urban form of Nagpur shared many similarities with Colombo, Sri Lanka, in terms of low-rise development and presence of lightweight structures (Emmanuel, 2016; Perera & Emmanuel, 2016). Kotharkar and Bagade (2017) presented LCZ map for Nagpur city, as shown in Fig. 2. It addressed some of the key issues presented in the Colombo case study. Their mapping technique identified many subclasses of LCZ present within the city revealing the heterogeneous arrangement of built LCZs. The major percentage of built land cover was covered by the LCZ 3 followed by LCZ 9, LCZ 6 and LCZ 6_5 altogether constituting more than 80% of built LCZs in Nagpur city. These major LCZ were revisited and studied in detail by field campaign. It examined the parameters retrieved from the secondary data which includes percentage of vegetation cover, sky-view factor, pervious-impervious fraction and changes in built form. It was