Science of the Total Environment 650 (2019) 1805–1817

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

The exposure of slums to high temperature: Morphology-based local scale thermal patterns

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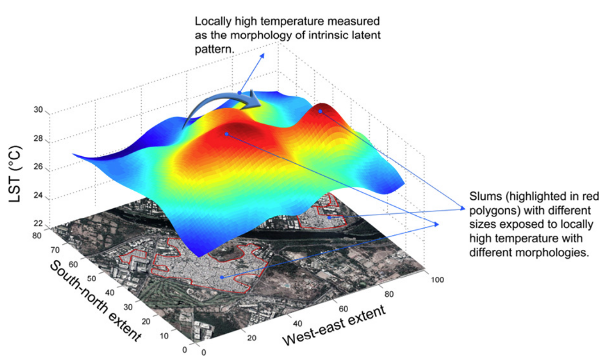
HIGHLIGHTS

- A workflow of investigating local scale temperature patterns is proposed.
- Morphological parameters characterize the intrinsic temperature patterns without the restriction of the pixel size.
- In particular, slums are exposed to locally high temperature.
- Larger slums tend to be exposed to more intense locally high temperature.

GRAPHIC ABSTRACT



ARTICLE INFO

Article history:
Received 25 May 2018
Received in revised form 23 September 2018
Accepted 25 September 2018
Available online 26 September 2018

Editor: SCOTT SHERIDAN

Keywords:
Slums
Local scale
LST
Morphological patterns
MODIS
Ahmedabad
India

ABSTRACT

Heat exposure has become a global threat to human health and life with increasing temperatures and frequency of extreme heat events. Considering risk as a function of both heat vulnerability and hazard intensity, this study examines whether poor urban dwellers residing in slums are exposed to higher temperature, adding to their vulnerable demographic and health conditions. Instead of being restricted by sampling size of pixels or other land surface zones, this study follows the intrinsic latent patterns of the heat phenomenon to examine the association between small clusters of slums and heat patterns. Remotely sensed land surface temperature (LST) datasets of moderate resolution are employed to derive the morphological features of the temperature patterns in the city of Ahmedabad, India at the local scale. The optimal representations of temperature pattern morphology are learnt automatically from temporally adjacent images without manually choosing model hyper-parameters. The morphological features are then evaluated to identify the local scale temperature pattern at slum locations. Results show that in particular locations with slums are exposed to a locally high temperature. More specifically, larger slums tend to be exposed to a more intense locally high temperature compared to smaller slums. Due to the small size of slums in Ahmedabad, it is hard to conclude whether slums are impacting the locally high temperature, or slums are more likely to be located in poorly built places already with a locally high temperature. This study complements the missing dimension of hazard investigation to heat-related risk analysis of slums. The study developed a workflow of exploring the temperature patterns at the local scale and examination of heat exposure of slums. It extends the conventional city scale urban temperature analysis into local scales and introduces morphological measurements as new parameters to quantify temperature patterns at a more detailed level.

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https://doi.org/10.1016/j.scitotenv.2018.09.324
0048-9697/

1. Introduction

1.1. Excessive heat and extreme heat events

The global temperature keeps rising (Change, 2014) along with disproportionate variations leading to a change in the frequency of extreme climate events and causing the majority of the global land surface to experience an increase of extreme heat events (Stocker, 2014; Wigley, 2009). Even worse, as near-surface temperature is largely governed by the land surface specification, the built environment with more dense buildings, impervious surfaces, and less vegetation within urban areas exhibits a doubled warming rate of the global level (Stone et al., 2013). Such higher temperatures in urban areas, known as Urban Heat Islands (UHI) (Balchin and Pye, 1947), have been detected and documented for nearly 200 years (Howard, 1818, 1833). Their magnitude could be up to 12 °C in clear and calm weather condition (Landsberg, 1981; Oke, 1973, 1981; Oke, 1982). With the advancement of airborne sensors in monitoring land surface temperature (LST), the surface UHI is also considered as an important indicator of urban environment (Rao, 1972; Roth et al., 1989; Streutker, 2002, 2003; Voogt and Oke, 1997).

1.2. Discrepancies in local scale heat related risk analysis

With increasingly high temperatures in urban areas, a paradigm shift has can be observed from disaster response management to proactive risk management (Assembly, 2015; Change, 2014; Chu, 2015; Leal Filho, 2016). Due to the intra-urban heat risk variations within cities especially in developing countries, urban dwellers are more likely to be affected by heat-related morbidity and mortality risks (Kjellstrom et al., 2007; McGeehin and Mirabelli, 2001; Romero-Lankao et al., 2016). Thus feasible and effective risk management is recommended to be local level oriented and prioritized for groups with the highest heat risk (Baker, 2012; Chang et al., 2007; Chu, 2015; Larsen, 2015). Only a limited number of studies in South Asian cities such as Mumbai, Delhi, Ahmedabad and Surat in India localized the heat related risks by suggesting that slum dwellers are more vulnerable than others to extreme heat due to poor demographic, physiological and economic conditions (Hajat et al., 2005; Nag et al., 2009; Rathi et al., 2017; Romero-Lankao et al., 2016; Tran et al., 2013). These studies only addressed risks by exclusively focusing on the heat vulnerability in terms of socioeconomic attributes (Chaudhury et al., 2000; Dash and Kjellstrom, 2011). However, as risk is a function of hazard intensity and vulnerability of people exposed to the hazard (Blaikie et al., 2014; Brooks et al., 2005). Only one related study in Ahmedabad suggested that slum dwellers may experience a higher temperature by using a ground survey covering only a limited number of households (Knowlton et al., 2014). The local scale exposure pattern of vulnerable slum dwellers to high-temperature hazards in a whole city has never been examined.

It has been widely acknowledged that local scale temperature variations within urban areas should not be neglected due to the diverse intra-urban land surface specifications (Arnfield, 2003; Kalnay and Cai, 2003). Slums defined as areas lacking access to satisfactory water, sanitation, durable housing or tenure security (Un-Habitat, 2016), are with dense and poorly built forms and materials subject to extreme heat. Unfortunately, high temperature patterns such as the UHI phenomenon depicted either through *in-situ* measurements or satellite images are dominated by the "urban-rural" dichotomy, providing aggregated information at city or regional scales (Stewart, 2011a; Stewart, 2011b; Stewart and Oke, 2012). A handful attempts using thermal satellite images in examination of the local scale temperature variations are either restricted by the pixel level or averaging the pixel values into census tracts or districts bounded by road networks (Amiri et al., 2009; Buyantuyev and Wu, 2010; Chang et al., 2007; Connors et al., 2013; Coutts et al., 2016; Kroeger et al., 2018; Norton et al., 2015; Preston et al., 2011; Stewart and Oke, 2009; Svensson and Eliasson, 2002; Yin et al., 2018). These studies essentially focused on temperature values with different granularity instead of the intrinsic temperature patterns. One exception, focusing on local scale LST variation at the phenomenon level, is based upon visual identification of surface heat islands (Gulbe et al., 2017).

1.3. The temperature patterns of slum areas

Temperature patterns are essentially continuous in space and time hidden in noisy discrete observations in the form of *in-situ* measurements or satellite images, which should be recovered through modeling (Goodchild, 1987). The UHI at city or regional scale provides an inspiring concept for characterizing temperature patterns through spatial or morphological parameters such as extent, magnitude and location, and shows an association between these parameters and city size and location (Quan et al., 2014; Streutker, 2002, 2003). These morphological parameters capture the intrinsic patterns of the temperature phenomenon instead of being restricted by the pixel size or artificially defined land patch units. Recognizing such benefits, this study builds on the strength of morphological parameters to characterize the local scale temperature patterns. Similar to the city or regional scale UHI, the presence of slums are to be associated with local scale morphological features of temperature patterns such as "island-shaped" temperature bumps. Therefore, this study aims to answer: (1) whether slums are experiencing higher temperature compared to other built environments, and (2) how slums are associated with local scale temperature patterns?

2. Study area and data

2.1. Study area

The case study city of Ahmedabad, India is the sixth largest city of India with a population of approximately 5.6 million and less than 5% of the population lives in slums according to the census (Chandramouli and General, 2011). However, this statistic excludes a large part of physically deprived areas such as chawls that are working class housing of very poor conditions. Local data from the municipality conclude a much larger amount of population (around 18%) living in slum conditions, which also matches with insights we have from field visits (therefore this data is used as a reference in this study) (Garland, 2016). In general, such areas suffer from high temperature and frequent heat waves (Azhar et al., 2014). The average summer temperature is 38.8 °C through March to June. The heat waves can intensify the daily maxima during the hottest month of May, for instance, the worst heat wave in the recent history of Ahmedabad (in 2010) increased the temperature up to 46.8 °C (Knowlton et al., 2014).

The 56 × 44 km rectangular shaped study area encompasses the entire Ahmedabad municipality and its rural surroundings to represent land use and land cover diversity (Fig. 1). The coordinates of the northwestern and southeastern corners are "23.22 N, 72.31E" and "22.83 N, 72.84E", respectively. The municipal boundary along with the administrative wards is highlighted by black solid lines.

2.2. Data

Using dense automatic weather station (AWS) networks to observe near-surface air temperature is not possible in developing countries, where commonly only one AWS (distant from urban areas) can be found at the airport. Alternatively, the LST recorded by thermal satellite images with resolutions coarser than 250 m can be used as a strong indicator of the variation of near surface air temperature despite of distinctively different meteorological and thermodynamic processes between near surface air temperature and the LST (Coutts et al., 2016; Klok et al., 2012; Stoll and Brazel, 1992).