Urban Climate xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Urban Climate

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

Urban Heat Island studies in South Asia: A critical review

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ARTICLE INFO

Keywords:
Urban Heat Islands
South Asia
Critical review
Cities
Tropical Climate

ABSTRACT

South Asian cities are home to nearly 15% of the world's urban population. These cities are experiencing rampant environmental deterioration, making them vulnerable to the impacts of climate change phenomenon, one of which is urban-rural temperature difference known as urban heat island (UHI) effect. While South Asian UHI research publications have tripled since 2000, a comprehensive overview of the experimental results, significant advancements and predominant directions in research is necessary to add clarity to the scientific understanding of tropical and subtropical urban climates and also, to aid city planning and policy-making. A review of 85 original research publications from peer-reviewed journals and conference proceedings in last five decades, covering 28 representative South Asian cities, revealed that Delhi, Chennai and Colombo were most frequently studied and satellite imagery based thermal mapping was used predominantly. Results from few significant studies have shown practical implications for energy use and management, human health, comfort and productivity, reducing air pollution and urban land-use planning. With similar patterns of urbanization, geographies and climate types prevailing across international borders, cities in South Asian region could mutually benefit from collaborative multi-disciplinary research efforts and knowledge sharing to competently respond to and manage the detrimental impacts of urban heat islands.

1. Introduction

As urban populations expand unchecked and per capita incomes grow rapidly, the demand for basic urban amenities like housing, energy, transport, water, waste disposal and sanitation are increasing exponentially (UNEP; SAARC, 2009; World Bank Group, 2015). With climate change at bay, urban growth and resource management is a major challenge to the rising economies, especially in the developing countries. South Asia, defined geographically as the region of Asia that includes Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka, holds 1.6 billion people, almost one quarter of the world's current population. Recent population projections suggest that by 2050, the population of South Asia will approximate or exceed 2.2 billion people (International Institute for Applied Systems Analysis, 2012).

South Asian regions are facing urban sustainability challenges on two front - existing and upcoming. Existing urban challenges includes poverty, rising GHG emissions, pollution concentrations and growing energy demands. South Asia is home to 45% of the world's poor people, living at or below $2 a day (Sumner, 2012), making it more vulnerable to climate impacts. Greenhouse gas (GHG) emissions have doubled in India and Pakistan between 1990 and 2012, with urban areas responsible for over 60% of the increase (The World Bank, 2017, 2010). 11 out of top 20 cities with highest concentration of pollutant ($PM_{2.5}$) belongs to South Asia region (World Health Organization, 2017). Energy consumption of this region went up to 64% between 1994 & 2002 (Lahiri-Dutt,

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https://doi.org/10.1016/j.uclim.2017.12.006
Received 6 July 2017; Received in revised form 26 October 2017; Accepted 18 December 2017

Please cite this article as: Kotharkar, R., Urban Climate (2018), https://doi.org/10.1016/j.uclim.2017.12.006

2006). The upcoming challenges include mitigating the very likely increase in winter temperatures as well as frequency of extremely hot days and nights during the summer (IPCC, 2013). Chan et al. (2012) studied excess mortalities in cities such as Hong Kong, Bangkok, and Delhi and its findings suggest that mortality increases from 4.1% to 5.8% per 1 °C over a temperature threshold of approximately 29 °C.

Faced with the intimidating prospect of irreversible climate change and rampant environmental deterioration, scientific enquiry into the effects of anthropogenic activities and land-use change on urban climate can potentially uncover extensive practical implications for energy use and management, human health, comfort and productivity, urban ecology, reducing air pollution and therefore, a more sustainable urban development (Grimmond et al., 2010; Roth, 2013).

Urban Heat Island (UHI) effect can be described as temperatures observations in towns and cities that are generally higher than in surrounding rural or suburban areas (Oke, 1982). It is also a mechanism that is associated with urban climate impact. UHIs have been proved to occur as a result of the introduction of artificial surfaces, such as buildings and roads made of dry and impervious construction materials, along with human activities that radically alter the energy balance in cities and the atmospheric layers above (Erell et al., 2011; Oke, 1973; Roth, 2013). It exacerbate impacts by affecting rainfall patterns (Collier, 2006), interacting with and worsening air pollution (Xu et al., 2014), increasing flood risk and decreasing water quality (Hester and Bauman, 2013). However, the most direct impact of the UHI on human health is through exposure to increased temperature, which can be particularly problematic during heat waves. The current paper addresses the urban heat island (UHI) effect, which is perhaps the most palpable local climate change phenomenon in tropical and sub-tropical cities.

Due to the bio-physical nature of cities and the multi-layered structure of the atmosphere above them, four distinct types of heat islands have been identified at the micro, local and *meso* scales (Erell et al., 2011; Roth, 2013). At the micro-scale (1–100s m), subsurface and surface heat islands are primarily observed in the daytime and have been observed to affect the temperature of storm water runoff, groundwater characteristics, health of aquatic ecosystems and carbon exchange between soil and atmosphere (Roth, 2013). Studies of the canopy-layer of the atmosphere, found below the tops of buildings and trees, at the local scale (1- < 10 km) have reported the presence of “cool islands” due to shading from tall buildings during the day accompanied by a reciprocal heat island a few hours after sunset (Chow and Roth, 2006; Oke, 1988; Roth, 2013). Apart from affecting the thermal comfort of urban dwellers, the canopy-layer UHI has wide-ranging impacts on building energy use, water use for irrigation, thermal circulation, air quality and urban ecology (Roth, 2013). In the urban boundary-layer, that extends tens of kilometers above the tops of buildings, only weak heat islands that decrease as one moves further away from the city have been reported (Roth, 2013). However, the boundary-layer UHI can still potentially affect regional climate patterns, local circulation, precipitation, thunderstorm activity downwind and plant growing season (Roth, 2013).

Depending on the type and scale of heat island to be studied, various observational and modeling approaches have been adopted to study UHI. Spatio-temporal changes in surface temperature are best captured by the thermal scanners on aircrafts and satellites while fixed weather stations and automobile traverse surveys have been used to record ambient air temperature in the atmosphere (Arnfield, 2003; Mirzaei and Haghighat, 2010; Roth, 2013; Runnalls and Oke, 2000). Physical, statistical and numerical meteorological models have been developed to simulate the energy balance of urban areas and predict weather patterns at varying resolutions (Arnfield, 2003; Roth, 2013).

Since urban heat islands are a global phenomenon, their examination has increased exponentially in the past few decades, reflected in the remarkably rapid growth of available literature on the subject (Arnfield, 2003). However, inquiry into the thermal environment of low-latitude cities in the tropics and sub-tropics had been missing from mainstream UHI research until as recent as the 1950s (Roth, 2013) and therefore, only a handful of studies from South Asian cities were accounted for in previous reviews of UHI literature (Table 1).

Despite the modicum of South Asian UHI studies listed in past reviews, a simple web search of online databases pulls up over a hundred publications, indicating that a substantial amount of research is indeed underway in the region. At this stage, a comprehensive overview of the experimental results, significant advancements and predominant directions in South Asian UHI research is necessary to add clarity to the scientific understanding of tropical and subtropical urban climates and also, to aid city planning and policy-making. This paper aims to address this lacuna by critically reviewing the existing research on UHI in the South Asian region, systematically assessing their practical implications while also directing the scientific community towards areas in dire need of investigation.

2. Methods

Since the study of UHIs, their causes and effects are still at a nascent stage in the tropics and subtropics (Roth, 2007), it was anticipated that the current body of research focused on South Asia, a region comprised entirely of developing countries, would be relatively few in comparison to the more developed countries along the same latitudes.

The literature review began by retrieving a total of 120 research papers on the topic of UHIs in South Asian cities from numerous international and national scientific databases accessible online. Prior to the review process, strict eligibility criteria were applied and only a representative sample of peer-reviewed original research was retained for further analysis (refer Fig. 1). Research papers that did not satisfy one or more of these criteria were subsequently rejected from the sample.

The primary criteria dictated that only studies from cities and urban agglomerations in South Asian region were included in the sample. The second criteria focused on screening papers based on their source of publication and only original or ‘primary’ research published in international or regional peer-reviewed journals were deemed suitable for this review. An exception was made to include relevant studies presented at editions of the International Conference on Urban Climate (ICUC) and International Conference on