Science of the Total Environment 506–507 (2015) 453–465

Contents lists available at ScienceDirect

Science of the Total Environment

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

Impact of urbanization and land-use/land-cover change on diurnal temperature range: A case study of tropical urban airshed of India using remote sensing data

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HIGHLIGHTS

- Significant converging trend of DTR observed across Delhi during 2001-2011
- Annually averaged DTR of entire Delhi reduced from 12.48 °C to 10.34 °C
- Converging trend of DTR infers a net increase in the heat-related mortality rates
- DTR of urban areas was below 11 °C while that of rural areas was above 13 °C

ARTICLE INFO

Article history:
Received 17 July 2014
Received in revised form 20 October 2014
Accepted 2 November 2014
Available online xxxx

Editor: Simon Pollard

Keywords:
Diurnal temperature range
Land surface temperature
Urban heat islands
Remote sensing
GIS
Delhi

ABSTRACT

Diurnal temperature range (DTR) is an important climate change index. Its knowledge is important to a range of issues and themes in earth sciences central to urban climatology and human–environment interactions. The present study investigates the effect of urbanization on the land surface temperature (LST) based DTR. This study presents spatial and temporal variations of satellite based estimates of annually averaged DTR over megacity Delhi, the capital of India, which are shown for a period of 11 years during 2001–2011 and analyzes this with regard to its land-use/land-cover (LU/LC) changes and population growth. Delhi which witnessed massive urbanization in terms of population growth (decadal growth rate of Delhi during 2001–2011 was 20.96%) and major transformations in the LU/LC (built-up area crossed more than 53%) are experiencing severity in its micro and macroclimate. There was a consistent increase in the areas experiencing DTR below 11 °C which typically resembled the 'urban class' viz. from 26.4% in the year 2001 to 65.3% in the year 2011 and subsequently the DTR of entire Delhi which was 12.48 °C in the year 2001 gradually reduced to 10.34 °C in the year 2011, exhibiting a significant decreasing trend. Rapidly urbanizing areas like Rohini, Dwarka, Vasant Kunj, Kaushambi, Khanjhawala Village, IIT, Safdarjung Airport, etc. registered a significant decreasing trend in the DTR. In the background of the converging DTR, which was primarily due to the increase in the minimum temperatures, a grim situation in terms of potentially net increase in the heat-related mortality rate especially for the young children below 15 years of age is envisaged for Delhi. Considering the earlier findings that the level of risk of death remained the highest and longest for Delhi, in comparison to megacities like Sao Paulo and London, the study calls for strong and urgent heat island mitigation measures.

1. Introduction

With the onset of urbanization there has been a substantial change in the entire urban fabric which has resulted into many environmental changes such as narrower diurnal temperature range or DTR (Runnalls and Oke, 2000). DTR is an important index of climate change (Karl et al., 1984) and is susceptible to urban effects (Intergovernmental Panel on Climate Change, 2001). It is also affected by land use changes (Kalnay and Cai, 2003), vegetation (Collatz et al., 2000), soil moisture, clouds (Dai et al., 1999; Trenberth, 2003; Stone and Weaver, 2003), aerosols (Huang et al., 2006; Stenchikov and Robock, 1995) and solar radiation (Wild, 2009; Makowski et al., 2008). Urbanization has increased the concentration of the tropospheric aerosols that has influenced the local climate and also played an important role in decreasing the DTR. This happens because of the well known 'urban heat island effect' which prominently takes place at night when buildings and streets release the solar heat absorbed during the day and lower sky-view factor trapping that heat within the urban canopies thereby increasing the

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http://dx.doi.org/10.1016/j.scitotenv.2014.11.006
0048-9697/

Table 1
Details of the locations across Delhi selected for investigation.

No.	Station name	Station code	Latitude	Longitude	Type of urban canopy/land-use land-cover
1.	Sitaram Bazar*	SB	28.648	77.228	Dense canopy
2.	Adarsh Nagar*	AN	28.718	77.175	Medium dense urban canopy — I
3.	Rohini*	RN	28.720	77.083	
4.	Parmanand Hospital*	P Hos	28.710	77.207	
5.	Kaushambi*	K	28.643	77.320	
6.	Connaught Place*	CP	28.635	77.220	
7.	Janakpuri*	JP	28.633	77.096	
8.	Dwarka*	Dwarka	28.591	77.057	
9.	Bhikaji Cama*	BC	28.568	77.189	
10.	Lajpat Nagar*	LN	28.562	77.237	
11.	Neb Sarai*	NS	28.512	77.202	Medium dense urban canopy — II
12.	Inter-State Bus Terminus	ISBT	28.669	77.230	
13.	New Moti Nagar*	NMN	28.662	77.141	
14.	Red Fort	RF	28.656	77.241	
15.	Parliament House	PH	28.617	77.208	
16.	Safdarjung Airport	SAF	28.584	77.206	
17.	Yusuf Sarai*	YS	28.563	77.207	
18.	Okhla Extension Terminal	OET	28.547	77.307	
19.	Chirag Delhi*	CD	28.540	77.229	
20.	Vasant Kunj*	VK	28.517	77.160	
21.	Kauturi Ram College	KRC	28.840	77.093	Less dense urban canopy
22.	Bhavan Industrial Area	BIA	28.788	77.059	
23.	Indian Institute of Technology*	IIT	28.547	77.191	
24.	NTPC Badarpur*	NTPC	28.520	77.295	
25.	Asola Wild-life Sanctuary	AWS	28.448	77.234	Medium dense forest
26.	Buddha Jayanti Park*	BP	28.616	77.179	
27.	Sanjay Van*	SV	28.534	77.188	
28.	Raj Ghat	RG	28.641	77.248	Park and garden
29.	Lodi Garden	LG	28.592	77.219	
30.	District Park*	DP	28.557	77.190	
31.	Kanjhawala Village	KV	28.734	77.006	Urban outskirts (resembling rural areas)
32.	Mundhela Kalan	MK	28.612	76.895	
33.	Ghumanhera Village	GV	28.532	76.926	
34.	Jawaharlal Nehru University*	JNU	28.550	77.165	Open area
35.	Najafgarh Jheel	NJ	28.508	76.942	Riverside area
36.	Majnu Ka Tila*	MKT	28.697	77.228	

(* stations which were earlier considered in the field campaigns conducted by Mohan et al. in the year 2008 and 2010) (Mohan et al., 2012, 2013).

night-time temperatures. The slight cooling which happens in the daytime owing to the shading effect, presence of aerosols etc. further helps in inducing lower values of DTR. As more and more areas across the world are getting urbanized, a downward trend of the global and local DTR has been observed (Kalnay and Cai, 2003; Jones et al., 1999; Easterling et al., 1997; Vose et al., 2005; Wang et al., 2012; Sun et al., 2006).

Till recently, most of the information on DTR came from station observations of surface air temperature or from numerical model simulations. Station observations are sparse, unevenly distributed and suffer from differences in elevation, time of observation and nonstandard siting (Peterson, 2003). Thus it is of larger interest to use satellite for evaluating DTR because of their ability to provide consistent and full spatial coverage for large areas over a period of time (Gallo and Owen, 1999). It is in this background, the present study of assessing the changing DTR over megacity Delhi using remote sensing data has been undertaken as it has witnessed an exponential rate of urbanization with major transformations in the land use/land cover (Mohan et al., 2011a). The current study supersedes the previous temperature studies (eg. Mohan et al., 2011b, 2014; Kumar and Hingane, 1988; Kumar et al., 1994) done over Delhi with the surface air temperature data of few locations and presents a comprehensive analysis of the spatio-temporal variation of the DTR across Delhi having deeper implications in evolving measures for improving the local urban climate thereby reducing the heat-related mortality rates.

2. Study area

The present study has been carried out on Delhi, the capital city of India located between the 28°24′17″N and 28°53′00″N latitudes and 76°48′30″E and 77°21′30″E longitudes. Delhi which is situated near the western bank of river Yamuna spreads over an area of around 1490 km^2. It is surrounded by the Himalayas in the North and the Aravali ranges in South-West. Delhi has typical tropical climate. Summers are extremely hot with temperatures reaching up to 45 °C, while winters are extremely cold with temperatures dipping down to 2 °C or even less in extreme cases. Average annual rainfall over Delhi is about 61 cm, most of which occurs during the monsoon months of July to September (Pandey et al., 2012). Delhi is one of the many megacities of the world struggling with rapid urbanization and gigantic levels of pollution from industrial, residential and transportation sources (Mohan et al., 2007). It has witnessed an accelerated rate of urbanization which is evident from the increasing population viz. 9.42 million in 1991, 13.78 million in 2001 and 16.75 million in 2011 (Delhi Statistical Hand Book, 2009; Census of India, 2011). The rapidly increasing population has significantly altered land use pattern and as on year 2008, the share of built-up area in Delhi has reached around 53% (790 sq km) (Mohan et al., 2011a). These changes in the LU/LC have significantly altered the micro and macroclimate of Delhi.

3. Data used

For the present study, remotely sensed annually averaged land surface temperature (LST) data for the nighttime and daytime has been used for a period of 11 years (2001–2011). The annually averaged LST data has been retrieved from the Monsoon Asia Integrated Regional Study program which utilizes Terra and Aqua Moderate-Resolution Imaging Spectroradiometer (MODIS) with 1 km spatial resolution. This dataset consists of 8-day period averages of land surface temperature and is available from the online database of Goddard Earth Sciences