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Spatial variations of intra-city urban heat island in megacity Delhi

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ABSTRACT

This study examines the variation of intra-city Urban Heat Island (UHI) in megacity Delhi by the mobile transverse measurement technique and spatial maps of UHI along the mobile routes have been generated for the city by using the ordinary kriging interpolation tool of ArcGIS. Meteorological data was collected by mobile surveys under clear sky weather days in monsoon and winter months of 2014 using two HOBO data loggers installed on a vehicle along the routes which covered many parts of Delhi intersecting vertical and horizontal transects capturing different land use patterns of the city. UHI values obtained through interpolation were validated with UHI obtained from temperature measurements at five fixed sites spread over the Delhi region, which were found in good agreement (R^2 = 0.91). The variability existing in the two seasons studied has been shown by low UHI values obtained in the monsoon season and high UHI values in winter season. The diurnal pattern of UHI showed higher UHI during the nighttime period, compared to morning and noon periods. The results show variable UHI in different regions of Delhi covered by mobile routes with high UHI values of > 6 °C observed during the winter period.

1. Introduction

The process of urbanization produces changes in the surface and atmospheric properties of the region forming a distinct local climate in the cities called as urban climate. Urban climate which can be understood as a local perturbation of the regional climate has climatic conditions that are different from the surrounding rural areas (Oke, Zeuner, & Jauregui, 1992). Human settlements and urban development transform the land use/land cover (LULC) in an urban area, thereby modifying the natural surface, altering the energy balance of the region and create undesirable thermal impacts. The impact of the urban climate is most evidently manifested in the increase of temperature of the air close to the ground as compared to its surrounding rural areas. This phenomenon is called the urban heat island (UHI) effect (Jauregui, 1997; Synnefa et al., 2008). Due to its importance in affecting the ecosystem, climate and life styles, UHI has been the focus of many studies worldwide, especially in tropical and subtropical regions (Cailhua, Yonghong, Weijun, & Cheng, 2011; Memon, Leung, & Liu, 2009; Xiao, Zhao, Li, & Yin, 2006). The results reported by Klysik and Fortuniak (1999) in their study for Lodz, Poland, in which UHII of 4–8 °C during nighttime in the summers was found and spatial structure of heat island predominantly occurred on windless conditions in the town. Another study done by Kim and Baik (2002), for Seoul, South Korea, have used the temperature data from two meteorological observatories and reported the frequent occurrence of maximum UHI intensity during nighttime, as compared to the daytime. Urbanization is increasing at a rapid rate, and the major contributing factors are industrialization, education and employment opportunities besides social factors such as attraction of cities and desire for a better standard of living thus, UHI has become a very important issue for environmental monitoring.

India is also among the nations which are witnessing sharp urban growth. According to the 2011 Census of India, the urban population grew from 286 million in 2001 to 377 million in 2011 showing a growth rate of 2.76% per annum during 2001–2011. The megacities of India like Mumbai, Delhi, Chennai and Hyderabad tops the list of Indian cities with a huge urban population (Census of India, 2011). Such cities with dense urbanization need to be studied for urbanization impact studies such as urban heat island phenomenon. Some landuse landcover studies have been reported in Delhi such as by Rahman, Kumar, Fazal, and Siddiqui (2012) and Singh and Singh (2014) which indicated the transformation of the natural landscape and increase in built up area due to increasing urbanization. In an earlier study, Yadav, Sharma, Peschin, and Masiwal (2017) compared the temperatures and landuse/landcover features between two locations of Delhi and found the existence of intra-city UHI of the order of 2.8–3 °C in areas having lesser vegetation and lower value of Normalized Difference Vegetation Index (NDVI). In another study, Grover and Singh (2015) found low surface UHI for green pockets of Delhi. By using temperature data from four

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meteorological stations, namely Safdarjung, Palam, Gurgaon and Rohtak in NCR region, Mohan, Kandya, and Battiprolu (2011) have found the warming trends in temperatures in the National Capital Region (NCR) Delhi in past few decades after 1990. In another study, Mohan et al. (2012) have reported warmest pockets in Cannaught Place and Sitaram Bazaar in Delhi based on the temperature measurements carried out for three days in the month of May 2008. Using temperature data recorded by Automatic Weather Stations (AWS) installed at 13 sites in Delhi from May 2007 to June 2008, Roy, Singh and Kumar (2011) reported highest observed temperatures in the western and northern sections of Delhi. Among the various approaches to study the occurrence of UHI, mobile transverse measurement is one of the useful and effective technique to examine the variation of the heat island phenomenon within a city through measurement of direct and reliable air temperatures at street canopy levels (Liu et al., 2017). In a city, if fixed observatories are incapable of covering the city's geographical area due to their small numbers, the mobile measurement data can fill this inadequacy (Unger, Sumeghy, & Zoboki, 2001). For mobile measurement, temperature sensors are usually attached on the roof of moving objects. The basic temperature difference between the urban and its surrounding suburban or rural area is then calculated. One of the earlier mobile transverse measurement study was carried out in Tokyo in 1996 with the help of electric tram cars and it revealed the existence of three cliffs (i.e. steep temperature gradient at urban/rural boundary) in the heat island of metropolitan Tokyo (Yashmita, 1996). A study done by Busato, Lazarrin and Norro (2014) has used the mobile survey to study UHI in a medium size city of Italy and found UHI up to 6 °C in urban zones. Other mobile transverse measurements were conducted in Szeged, Hungary (Unger et al., 2001) Tel Aviv, Israel (Saaroni, Eyal, Arieh, & Oded, 2000), Debrecan, Hungary (Bottyan, Kircsi, Szegedi, & Unger, 2005), Hong Kong, China (Fung & Lam, 2009) and Singapore (Wong & Jusuf, 2008). Another study done by Deosthali (2000) gives the detailed horizontal structure of the heat and moisture islands of the Pune city, India, and the results indicate night time warming in the core of the city.

The present paper reports the detailed investigation of the spatial variation of intra city urban heat island in Delhi determined by mobile transverse measurement technique using a moving vehicle (equipped with temperature sensors and GPS). This is the first study to report the findings from the rigorous mobile transverse measurements carried out in the megacity having subtropical climate and witnessing fast urbanization in a developing country, and these mobile results have been used to generate the interpolated surface by kriging. Moreover, some of the values of modeled output generated from kriging, has been validated with that of UHI values obtained from the fixed stations located in the various parts of the city. The routes for mobile transverse measurements have been selected to cover the major areas of Delhi to the extent possible covering the different land use patterns in the city.

2. Study area

Delhi, the capital of India, located at 28°23′17″–28°53′00″ North latitude and 76°50′24″–77°20′37″ East longitude (Fig. 1). The city with a length of 51.9 km and width of 48.48 km covers an area of 1483 km^2. It is situated on the banks of Yamuna river. Delhi has a humid subtropical climate. In summer months (i.e. April–June), temperatures can rise to 45 °C followed by monsoon season which normally starts at the end of June and lasts until mid-September with the average rainfall ranging from 400 to 600 mm (Grover & Singh, 2015). Winter starts in late November with its peak in January during which temperature drops to about 4 °C. The city is witnessing continuous and rapid urbanization with a population of 9.42 million in 1991, 13.8 million in 2001 and 16.7 million in 2011. Out of Delhi's total area of 1483 km^2, 1113.65 km^2 is urban, and 369.35 km^2 is rural. About 97.5% people live in urban regions whereas only 2.5% live in rural areas of Delhi as per population census 2011.

3. Methodology

3.1. Data and software used

The types of data and the software used in the present study are given below:

1. Meteorological data: Ambient temperature data recorded at the frequency of 10 s from two HOBO data loggers (S. No. 10506046 and 10506047) mounted on the roof of the car and one HOBO data logger (S. No. 10506045) mounted on a tower inside the National Physical Laboratory (NPL) campus, which is located at the latitude of 28°38′14.66″N and the longitude of 77°10′11.93″E (Fig. 1), at 2 m height from the ground.
2. GPS point data recorded in GARMIN GPS (Model: eTrex Summit, position accuracy: < 15 m) in .gpx file format for real time positioning of the mobile vehicle on the routes undertaken.
3. Survey of India (SOI) Data: Vector polygon shapefile for district boundaries of Delhi.
4. ArcGIS 10.3.1 software and Geostatistical Analyst tool for developing spatial maps of UHI.

3.2. Calibration

The temperature sensors mounted on the moving vehicle for the mobile transverse measurement experiment were used after getting them calibrated from CSIR-National Physical Laboratory (NPL) which is the National Metrology Institute (NMI) of India and is the custodian of "National Standards" with a responsibility of the dissemination of measurements to the needs of the country. For temperature & humidity standards, it maintains the primary and secondary standards as per procedures of the International Temperature Scale of 1990 (ITS-90) and establishes the mutual compatibility of temperature standards within the country through international comparisons and disseminate the traceability of the laboratory to the users as a part of metrology service to the nation. The detail of the calibration is as follows:

a. As per the standard protocol, the environmental conditions were as 23 °C ± 2 °C and humidity as 55% ± 10% RH under which the calibration of temperature sensors was carried out.
b. Two pressure RH generator (Thunder Scientific-2500) was used for calibration of temperature sensors which had uncertainty of 0.3% RH and 0.02 °C. The standard used for calibration is traceable to Indian national standards.
c. During the calibration, hygrometer has been compared with standards of hygrometry maintained at CSIR-NPL.
d. The uncertainty of measurements for the hygrometer is ± 0.4% for RH and ± 0.2 °C for Temp. at 95% confidence level.
e. All the three sensors with S. No.10506046, 10506047 and 10506045 used in this study have been calibrated for the temperature ranges of 11.1–48.9 °C, 11.3–48.6 °C and 16–30 °C respectively and humidity ranges of 34.3–70.4%, 33.4–69.7% and 37–73% RH respectively.
f. The temperature data recorded by the three data loggers used in the study were harmonized by applying their respective calibration factors.

3.3. Mounting of temperature sensors

Among the three calibrated temperature sensors, the first two (S. No. 10506046 and 10506047) were mounted on the roof of the vehicle at 2 m height from the ground from the side of the car near the back side door using a specially designed attachment to avoid engine and exhaust heat; while the other one (i.e. S. No. 10506045) was installed in NPL campus at the same height (i.e. at 2 m) which was used as reference temperature for UHI calculations. The data loggers were housed in solar radiation shields to protect them from direct solar radiations as