Theor Appl Climatol (2016) 123:83–95
DOI 10.1007/s00704-014-1331-8

ORIGINAL PAPER

Spatial variation of temperature and indicative of the urban heat island in Chennai Metropolitan Area, India

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Received: 29 April 2014 / Accepted: 3 December 2014 / Published online: 23 December 2014

Abstract Heat island is the main product of urban climate, and one of the important problems of twenty-first century. Cities in tropical countries suffer extensively due to the urban heat island effect, and urban climate studies are necessary to improve the comfort level and city planning. Chennai is the tropical city; it is the fourth largest metropolis in India and one of the fastest growing economic and industrial growth centers in South Asia. The spatial distribution of heat intensity in Chennai Metropolitan Area was studied, and the influence of land use and green cover were analyzed in the present work. Mobile measurements were carried out throughout the study area using a grid network to represent various land use patterns of the city. The study revealed some heat and cool pockets within the city limit; the maximum intensities of temperature were noticed in the central core city and north Chennai, which are distinguished for their commercial centers and densely populated residential areas. In morning time, temperature differences between fringes and central parts of heat packets were in the range of 3–4.5 °C. Land use and green cover play a critical role in microclimate and influences it. Green cover has a significant negative correlation with observed microclimate variations. Thus, the study urges city administration, policy makers, and architects to take up effective mitigation and adaptation strategies in the city to make people more comfortable.

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1 Introduction

Cities are of special concern in a potentially warmer world because of the urban heat island (UHI) effect or microclimate (Oke 1973; Souch and Grimmond 2006). The heat island is the main product of the manifestation of urban climate and one of the important environmental problems of the twenty-first century (Rizwan et al. 2008). The observed temperature increases within cities exceed the predicted rise in global temperature for the next several decades (Grimm et al. 2008). Kalnay and Cai (2003) estimated that urbanization and other land use changes accounted for half of the observed reduction in diurnal temperature range and an increase in mean air temperature of 0.27 °C in the continental USA during the past century. Urbanization produces radical changes in the morphology and air composition of built-up areas leading to a modification of the local climate (Wanner and Hertig 1984). Some of the main factors related to UHI formation are the canyon radiative geometry, thermal properties of the materials, anthropogenic activities, and the urban greenhouse effect (Oke et al. 1991).

Many interactive thermodynamic properties of biophysical and built environments resulting from changes in these systems determine the spatial distribution of the UHI (Grossman-Clarke et al. 2005; Harlan et al. 2006). Land use and green cover play a vital role in spatial distribution of microclimate or heat island in urban area. Urban climate is influenced by many factors related to the intrinsic nature of a city such as its size, building density, and land use distribution (Oke 1982). The land use patterns are strong drivers of urban temperature. The presence and abundance of vegetation in urban areas was also recognized as a strong influence on the development of the urban heat island (Huang et al. 1987). Urban vegetation influences the physical environment of cities through selective absorption and reflection of incident radiation and regulation of latent and sensible heat exchange (Nichol 1996; Owen et al. 1998). While, in developing countries most of the urban development has been taken up with less attention on maintaining or increasing existing green cover of the city. The temporal and spatial variations in vegetation structure are analyzed using vegetation indices. Among the different vegetation indices studied, Normalized Difference Vegetation Index (NDVI) seems to provide the best results for vegetation analysis in urban environment (Shetty and Somashekar 2014). NDVI is found to be well correlated with physical climate variables including temperature, rainfall, and evapotranspiration in a wide range of environmental conditions (Gray and Tapley 1985; Cihlar et al. 1991; Sudipta and Menas 2004).

Tropical cities suffer extensively due to the urban heat island effect (Ahmed 2003). Roth (2007) had reviewed the nature and the intensity of the UHI in tropical and subtropical cities. There were number of observation based heat island studies in Asia indicated substantial variations in the development of UHI based on location, local topography, and these studies highlighted the profound role of urbanization (Padmanabamurthy and Bahl 1982; Sham 1987; Nasrallah et al. 1990; Chow and Roth 2006; Sen Roy et al. 2011). Furthermore, the natural climatic condition of hot-humid tropics experiencing hot weather, high humidity, and low wind velocity, often lead to thermal discomfort in outdoor environment (Emmanuel and Johansson 2006). The UHI in warmer climates likely increases thermal discomfort and associated heat-related maladies (Srivatsava et al. 2001; Merbitz et al. 2012). Some studies were performed on urban heat island intensity in India. The urban heat island intensity in Delhi was found to be significantly high during summer days for both afternoon and night hours. (Mohan et al. 2012). Ansar et al. (2012) documented UHI intensity in Thiruvananthapuram, and it was around 2.4 °C. A study by Borbora and Das (2014) in Guwahati city during summer time showed the difference in temperature intensity was above 2 °C. Ramachandra and Kumar (2010) concluded from their study that urban heat island seen in Bangalore was evident from large number of localities with higher local temperatures.

Chennai is a hot and humid city; each and every summer is acute and uncomfortable. In the past 60 years, during summer season the maximum temperature was increased about 1.9 °C, and the minimum temperature increased up to 1.3 °C (Jeganthan and Andimuthu 2013). Already two studies were attempted to find the heat intensities in Chennai (Jayanthi 1991; Amirtham and Monsingh 2008). However, these studies were limited to represent the overall study area, deficient in coverage of measurement sites, and not covering the various types of land uses. Hence, an attempt has been made to find the spatial variation of heat island in Chennai Metropolitan Area (CMA). The objectives of this article are twofold; the first objective is to find out the spatial variation of temperature in CMA and the second is to study the influence of city's land use and green cover with spatial heat intensity.

2 Study area

CMA is the fourth largest metropolis in India, and 33rd largest urban area in the world (Demographia 2013). It is a flat coastal, hot, and humid city located in the Bay of Bengal (Fig. 1) and capital of Tamil Nadu State. CMA is a highly densely populated city in India; urban agglomeration of the city goes nearly 8.6 million, and the city expands up to 1189 km^2. Population of CMA had grown rapidly in the last 20 years due to its major industrialization and tremendous growth. The Second Master Plan for CMA had projected the population of CMA to reach 11.2 million in 2021 and 12.6 million in 2026 (Sekar and Kanchanamala 2011).

CMA accounts for 16.21 % of the state income from all sectors. The manufacturing sector of CMA comprises large industries such as petrochemicals and chemical industries, electrical, automobile, and related ancillary industries. Recent trend shows that the economic structure of the city is tertiarised with growing contributions by Information Technology, Information Technology Enabling Service, and Business Process Outsourcing Industries. With the increase in economic activities the dependence on fossil fuel based energy sources, and consequent greenhouse gas emissions have increased rapidly in recent times.

The average meteorological parameters for the city are as follows: Annual mean maximum temperature is 32.8 °C, and the mean minimum temperature is 24.5 °C. May month is the hottest period in the year, which is used to term as "Agni Natchathiram period". May month's mean maximum temperature is 36.8 °C, and mean minimum temperature is 27.8 °C. The mean annual rainfall of the city is about 1300 mm; the annual mean relative humidity is 76 %, and the annual mean wind speed is 4.055 m/s.

3 Method

For urban spatial planning, a complete survey which represents all areas and land use patterns are needed. Previous heat island studies in Chennai were limited to

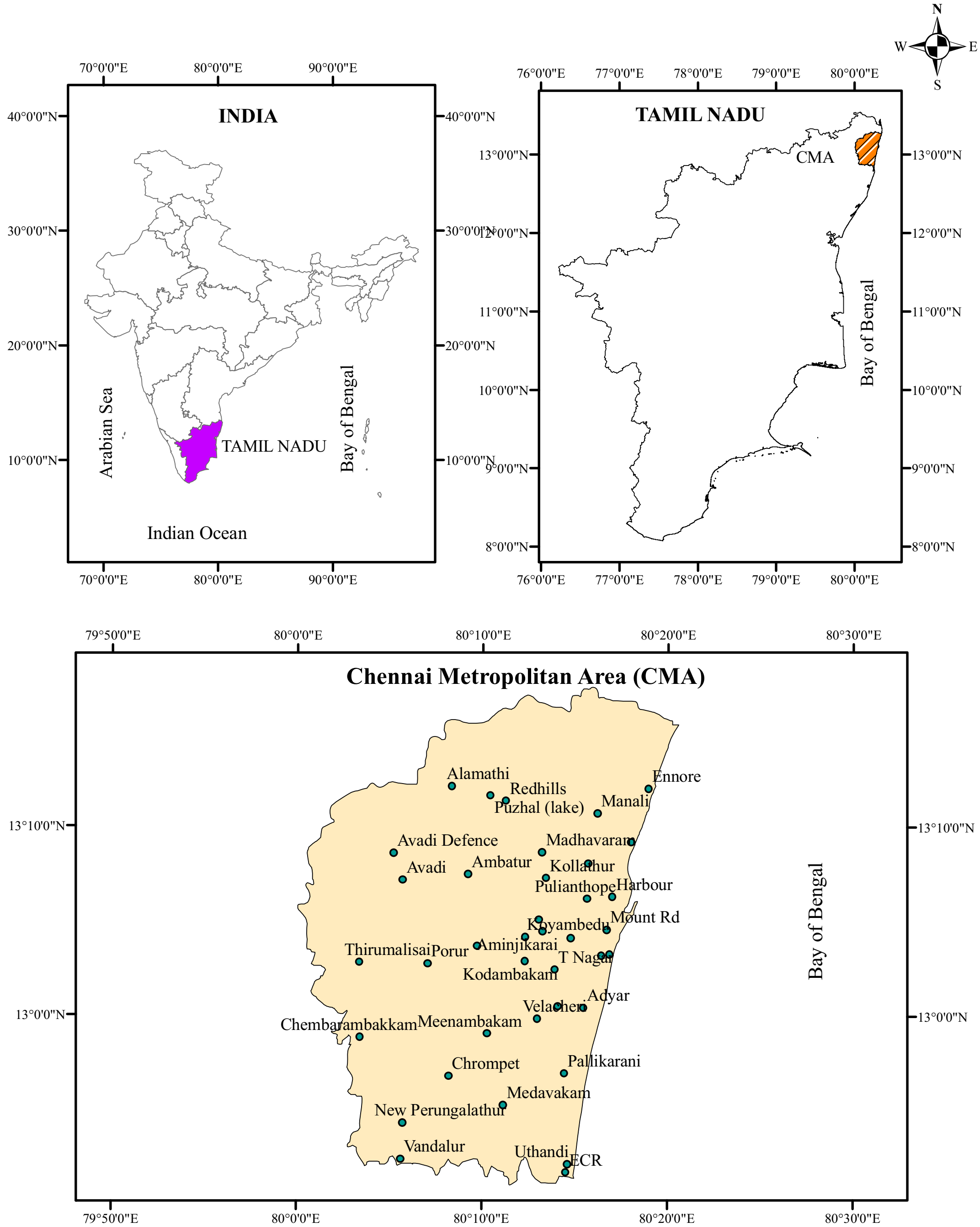

Fig. 1 Location map of Chennai Metropolitan Area

represent the overall area in a general way; to this point, survey had conducted using an equal grid size network throughout the CMA (Zsolt Bottya et al. 2005). The CMA was divided into a grid network of approximately 2.5× 2.5 km^2 (Fig. 2) which represents a wide variety of land use/land cover categories such as built-up areas, green areas, open space, and water bodies. Each grid was allotted at least one site for measurements to characterize the key land use in that particular grid, and in total 107 sites were chosen throughout the city. The CMA had divided into six routes, South East (SE), South West (SW), Middle East (ME), Middle West (MW), North East (NE), and North West (NW) for an access to take measurements.

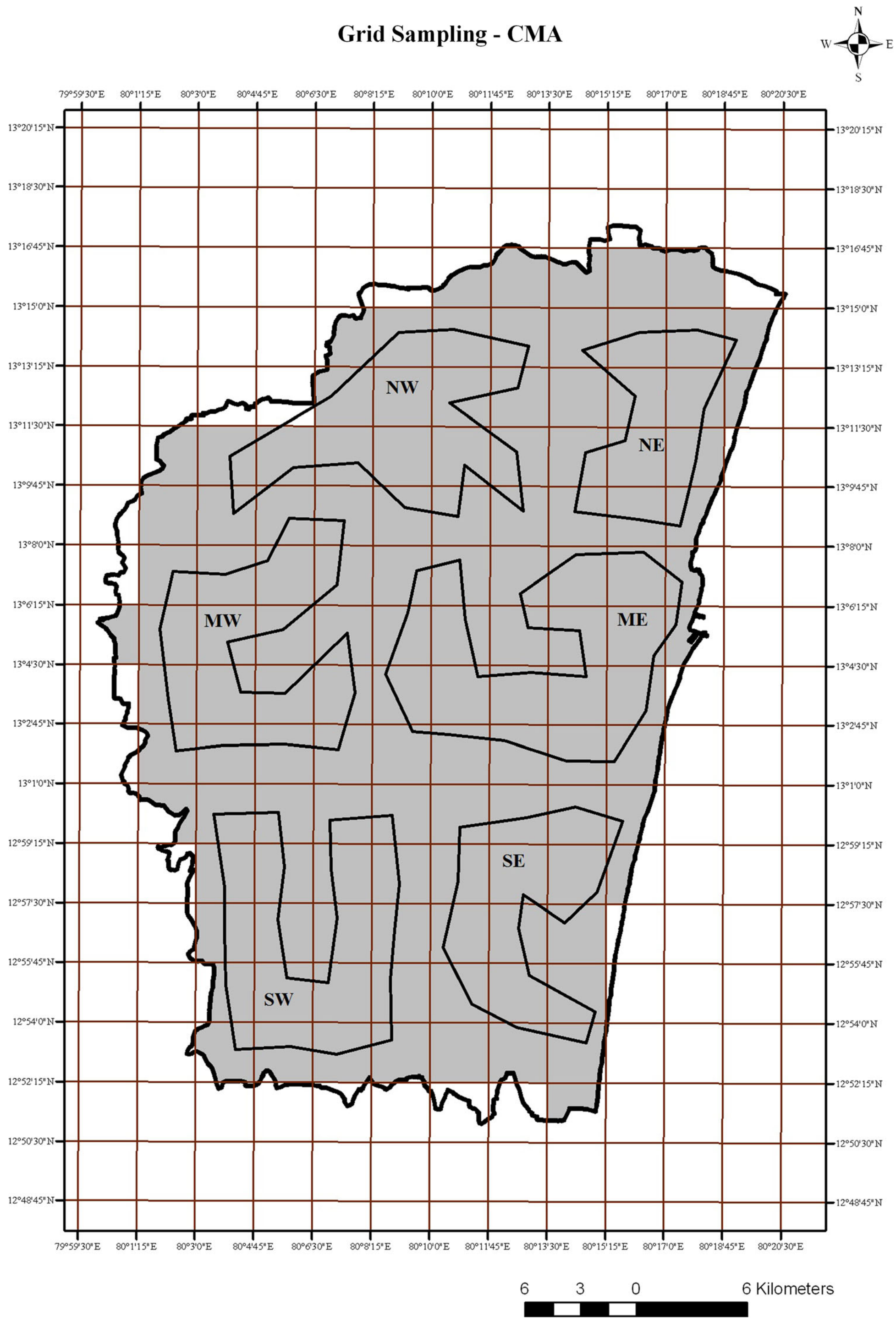

Fig. 2 Grid network of CMA used for UHI measurement

Six teams were arranged to carry out observations of dry and wet bulb temperature in six different routes. Measurements were taken both in early morning and in the evening for continuous seven days in Agni Natchatiram period (Hottest period of the year) from 25 to 31 May 2012 using Whirling Hygrometer (Zeal). These instruments were calibrated with India Meteorological Department (IMD) screen thermometer in the RMC (Regional Meteorological Centre), Chennai. In RMC, the instruments were compared at four different temperature ranges viz., 10–15, 20–30, 30–40, and 40–45 °C with screen thermometer and standardized.

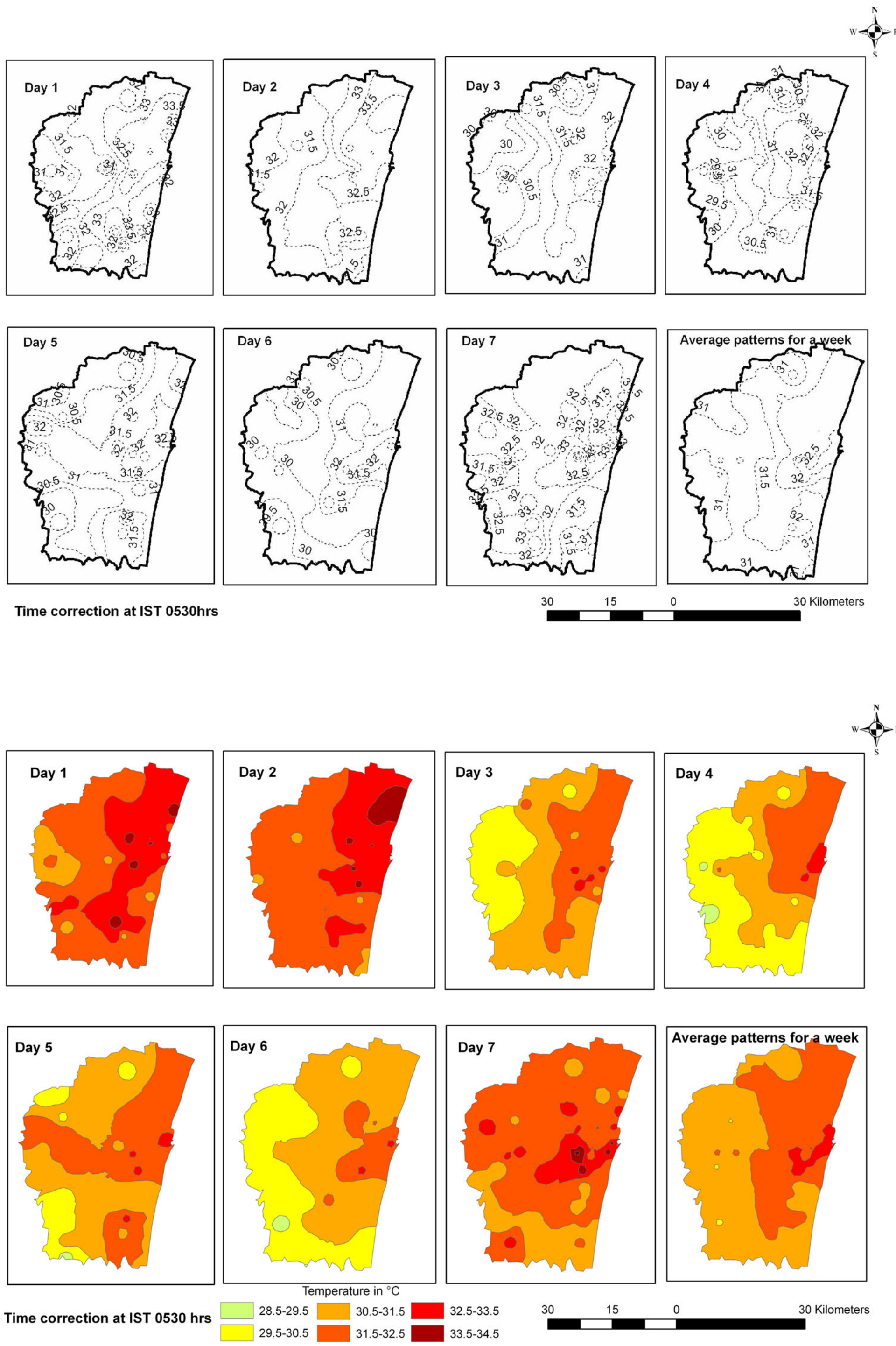

Fig. 3 Spatial distribution of temperature at IST 0530 hours during study period

Normally, air temperatures are measured at five ft. above the ground. The surveys in all the six routes started simultaneously around IST 0400 hours and IST 1300 hours and completed during the period of three h. For this time lag, corrections were applied in the readings based on the trend indicated by Thermographs of Nungambakkam and Meenambakkam stations, and the temperatures were corrected at IST 0530 hours and IST

1430 hours to make the observations comparable. The corrected temperatures were analyzed using GIS platform. Isotherms were constructed from readings taken during the study period to find the temperature distribution over the city, and also to locate heat islands within the city limit. The spatial pattern of heat intensity across CMA was plotted using spatial interpolation. Inverse Distance Weighting (IDW) method, which is the most likely method to produce the best estimation of a continuous surface of air temperature (Mookken et al. 2011) was used here for interpolation. The spatial distributions of heat intensity for all seven days were mapped in GIS to visualize, and carry out further analysis.

Then, land use and land cover (LULC) and vegetation cover of the CMA were studied to observe the relationship with microclimate of the study area. IRS LISS III digital data of a path 102 row 64 taken at 05.25 h on 1 September 2010 was acquired from NRSA, Hyderabad to study the present land use. The availability of cloud free data in the near period impulses to choose this image for land use study, and, there were no extreme events or cyclone damage occurred, and massive change of land use was also not recorded during the period of September 2010 to May 2012. Thus, the image was taken account to represent the land use patterns and green cover of study period. This image was processed using ERDAS IMAGINE 9.3 and digitized through ArcGIS 9.2 software. Six LULC classes were defined namely: agriculture land, barren land, forest cover, settlements, water bodies, and wetlands using supervised maximum likelihood classification and mapped spatially. The green cover of the city was observed using NDVI. The NDVI were calculated based on the spectral properties of the data under Indices Mode in ERDAS IMAGINE 9.3, and the obtained values were mapped, and visualized through GIS with appropriate ground truth verifications. The influences of land use and green cover with observed temperature were analyzed and correlation between temperature and NDVI was computed.

4 Results and discussion

The observed temperature of CMA during study period was between 29.5 and 34 °C in the morning hour (IST 0530) and 36–44.5 °C in the afternoon hour (IST 1430). The thermographs of Nungambakkam station showed the average temperature during the period between 25 May 2012 to 31 May 2012 was 31.2 °C, ranging between 30.7 and 31.7 °C at IST 0530 hours, and 41.3 °C with the range of 38–42.5 °C at IST 1430 hours. Figure 3 shows isotherms of temperature and its spatial distribution throughout the city at IST 0530 hours. The pattern of isotherms clearly indicated the presence of heat pockets over highly urbanized build up, and congested areas. The temperature difference between fringes and central parts of hot pockets were in the range of 3–4.5 °C during the study period. The observation indicated consistency in temperature magnitude on all the 7 days and slight day-to-day variations in extend of heat pockets.

The maximum intensity of temperature noticed in the central core city and north Chennai, which are distinguished for its commercial centers and densely populated residential areas. Compared with the earlier studies done by Jayanthi (1991) and Amirtham and Monsingh (2008) tremendous changes and increased heat pockets across the city were noticed. Jayanthi (1991) observed the temperature difference of 1.5 to 2.0 °C between the periphery and central areas of heat pockets. Amirtham and Monsingh (2008) noticed the existence of heat island of about 2.53 °C; the maximum temperature recorded was 31.58 °C, and the minimum temperature was 29.05 °C. The spatial

Table 1 Observed temperature range in Chennai Metropolitan Area and the places witnessed

Temperature range	Area
32.5–33.5 °C	Aminjikarai, Agasthya, George Town, Harbour, Medavakkam, Manali high road, Mount Road, Thousand Lights, and old Washermenpet
31.5–32.5 °C	Annanagar, Basin Bridge, Beach Road, Chrompet, Kodambakam, Koyambedu, Maduravayal, MarinaBeach, Meenambakam, Mint Road, Mylapore, Nanganallur, Nungambakkam, Pallikarani, Porur, Pulianthope, Ranganathapuram, Sathyamoorthy Nagar, Triplicane, and Velacheri
30–31.5 °C	Adyar, Anankaputhur, Chembarambakkam, East Coast Road, Raj Bhavan-Guindy, Mugapair west, Palanjur, Sithalabakkam, Sokkanallur, Sipcot, Thirumalisai, Uthandi, and Vandalur

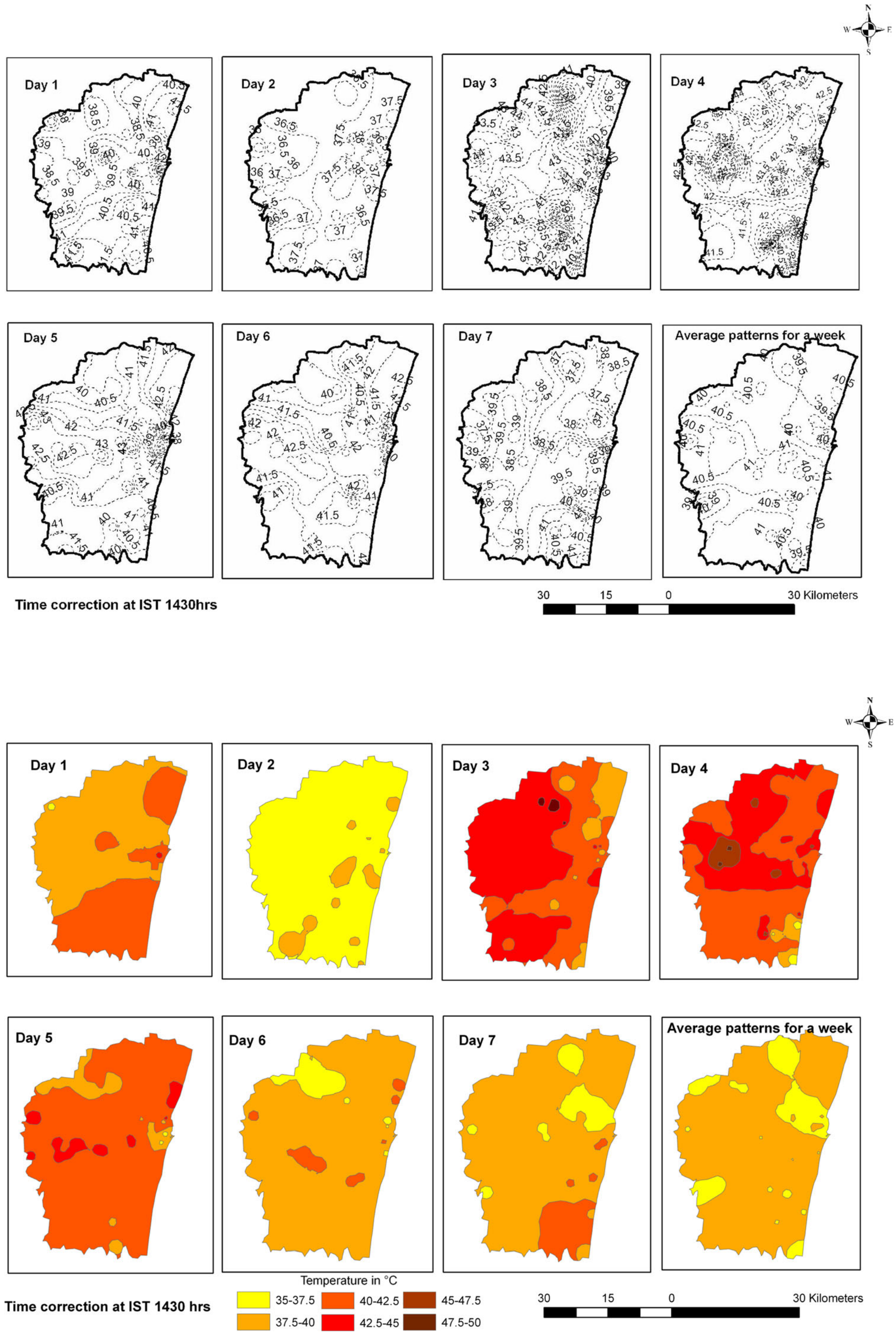

Fig. 4 Spatial distribution of temperature at IST 1430 hours during study period

intensity of urban heat will change as the city grows, and now this study implies the increasing tendency of heat intensity.

This study also reveals new heat pockets around Aminjakarai-Poonthamalee Highway, Medavakkam, T. Nagar, and Ennore. Aminjakarai is a highly urbanized zone,

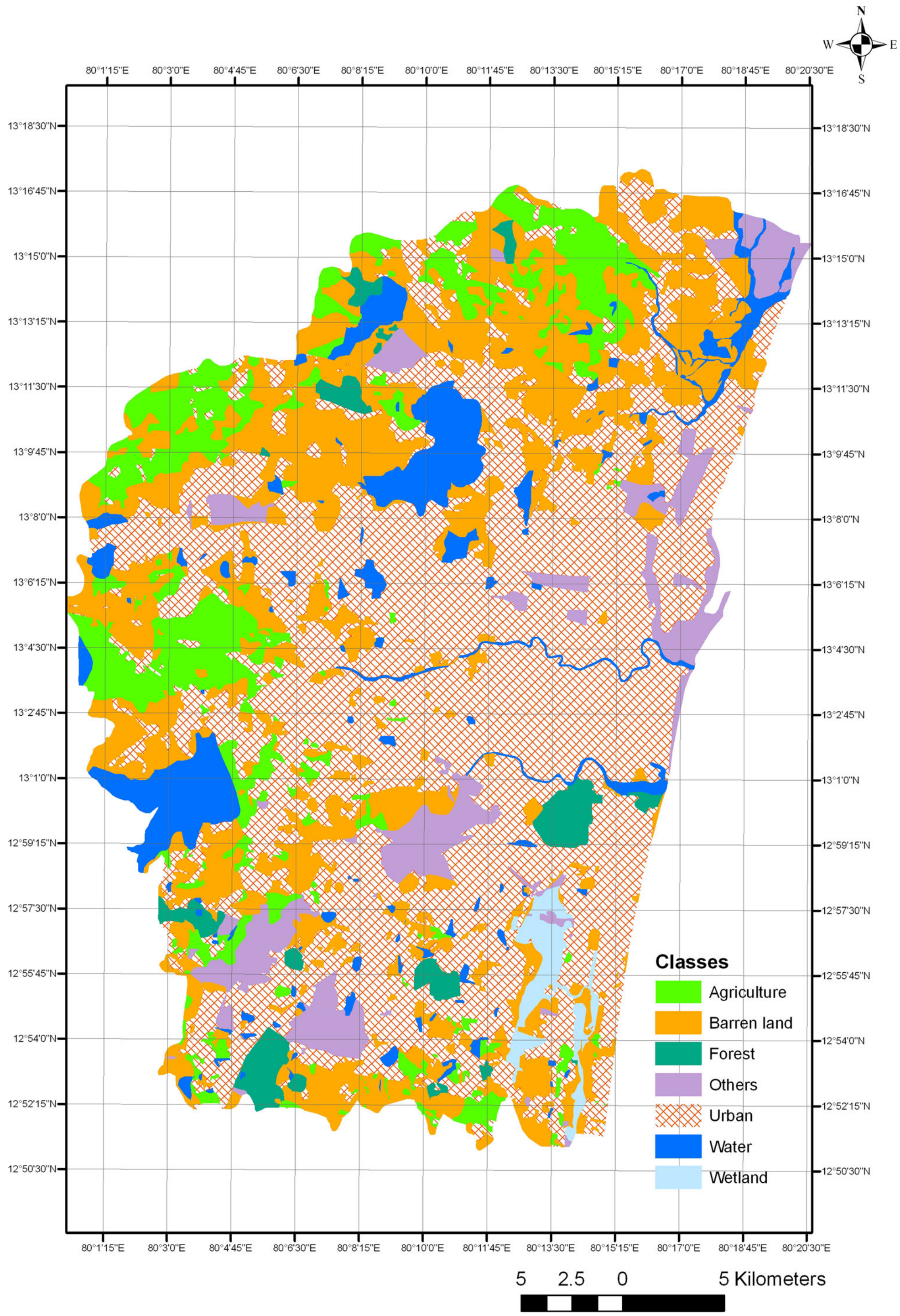

Fig. 5 Present land use land cover map of CMA

which has both commercial and residential neighborhoods. Medavakkam is an emerging urban centre due to the recent development of information technology and industrial sectors in the surrounding areas during the past decade. Two main landfills are situated nearby this area. T. Nagar area is a residential and well-known commercial area with floating population. Ennore is an industrial area, features a number of big manufacturing units.

These heat pockets were noticed with increased temperature up to 1.5–3.0 °C in the morning hours and 1.5–5.5 °C in the evening hours from the temperature recorded at thermographs of Nungambakkam station. In mornings, high-temperature level in the range of 32.5–33.5 °C was observed in most part of NE, ME, and some areas in SE Chennai. Moderate temperature level in the range of 31.5–32.5 °C was observed in most parts of NW, SW, SE, and MW. Lower temperature in the range of 30–31.5 °C was observed in some parts of SE, SW, MW, and NW Chennai. Table 1 lists the recorded temperature level at IST 0530 hours and the places it witnessed. It was interesting to note that this study had brought out some cool islands adjoining to green covers such as Alamathi, Raj Bhavan-Guindy, Tambaram Air Force, Vandalur and open spaces around Avadi defense, and Mettupalayam. The cool pockets were shown 1.5–3.0 °C lower than the temperatures recorded in thermographs.

Temperature surveys were also conducted during the afternoon period to study the intensity of heat islands during the period. Figure 4 shows the isothermal pattern and its spatial distribution at IST 1430 hours. The temperature distribution in the afternoon showed inconsistency, and there was no trend or pattern, confirming Parker's (Parker 2010) statement on UHI as it would be most pronounced on clear and calm nights. The temperature variation in afternoon was found in the range of 3.5–7.5 °C. In general, temperatures were high all over the city, and highest temperatures were observed over some interior places.

Figure 5 exhibits the present land use and land cover of CMA. Nearly half of the study area is fully urbanized; the settlement area occupied 47.7 % of the total CMA, followed by 25.1 % of barren land, 10.6 % of agriculture land, and 2.5 % of forest area. It is interesting to see that notable number of wetland bodies is also present in the study area, and about 1.2 % of the total area of CMA is wetland. The land use under "other" category includes industries and institutional lands. While, analyzing the land use patterns of CMA with observed microclimate at IST 0530 hours, agriculture and forest land use showed lower temperature in the range of 30.5–31.3 °C. The barren lands witnessed the temperature in the range of 30.3–31.6 °C, and the settlement area recorded the temperature in the range of 31.7–33.5 °C. Figure 6 depicts the spider diagram which elucidates the CMA's land uses and the average temperature recorded. Different land use in various parts of a city influenced local temperature (Gomez et al. 1998), and the warming was larger for areas that are built-up, industrial areas, and the better the vegetation cover the smaller the warmer trends (Yang et al. 2009).

The NDVI has been found to be a good indicator of surface radiant temperature (Nemani and Running 1989; Gallo et al. 1993; Gillies and Carlson 1995; Lo et al. 1997), and many studies have revealed direct relationship of the land surface temperature with the green cover of an urban area (Weng 2001; Weng et al. 2004). The NDVI of Chennai metropolis ranged from −0.78 to 0.48 (Fig. 7). Higher values were found in the south, southwest part of CMA, and Guindy where forest and dense vegetation had seen. The lower NDVI values corresponded to high dense built-up area in central and northern part of CMA, and water bodies. The medium NDVI values were observed over western and north western part of the image, where agricultural activities took place. The forest land use seemed to have the highest NDVI values in the range of 0.1 to 0.48, followed by agriculture land use with the values in the range of 0.2 to 0.23. Settlement had the NDVI values in the range of 0.3 to −0.12, and barren lands shown in the range of 0.2 to −0.19. Wetlands and water bodies behold the least values in the range of 0.1 to −0.7.

Figure 8 illustrates the correlation between the observed temperature at IST 0530 hours and green cover of CMA. It was interesting to note that strong significant correlation (r=0.30, p=0.01) between NDVI and temperature distributions was observed throughout the city. NDVI values were negatively correlated with the observed microclimate denoted the significance of green cover urban area. It was found in the study by Chen et al. (2006) that there was a negative correlation between NDVI and temperature when NDVI was limited in less than 0.6. But when NDVI reached 0.6 or more, where 100 % vegetation cover was identified, a linear positive correlation between NDVI and temperature was found. In our study, since the NDVI is limited to only 0.6, the negative correlation is the only possibility. Mallick et al. (2008) studied the green cover in Delhi

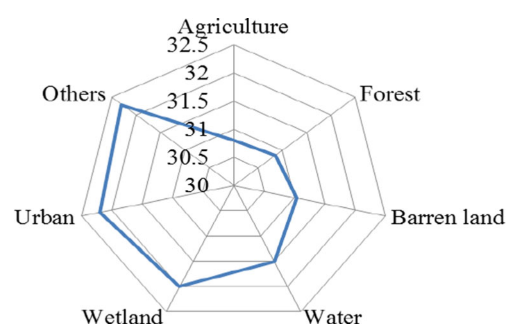

Fig. 6 Land uses and their average temperature

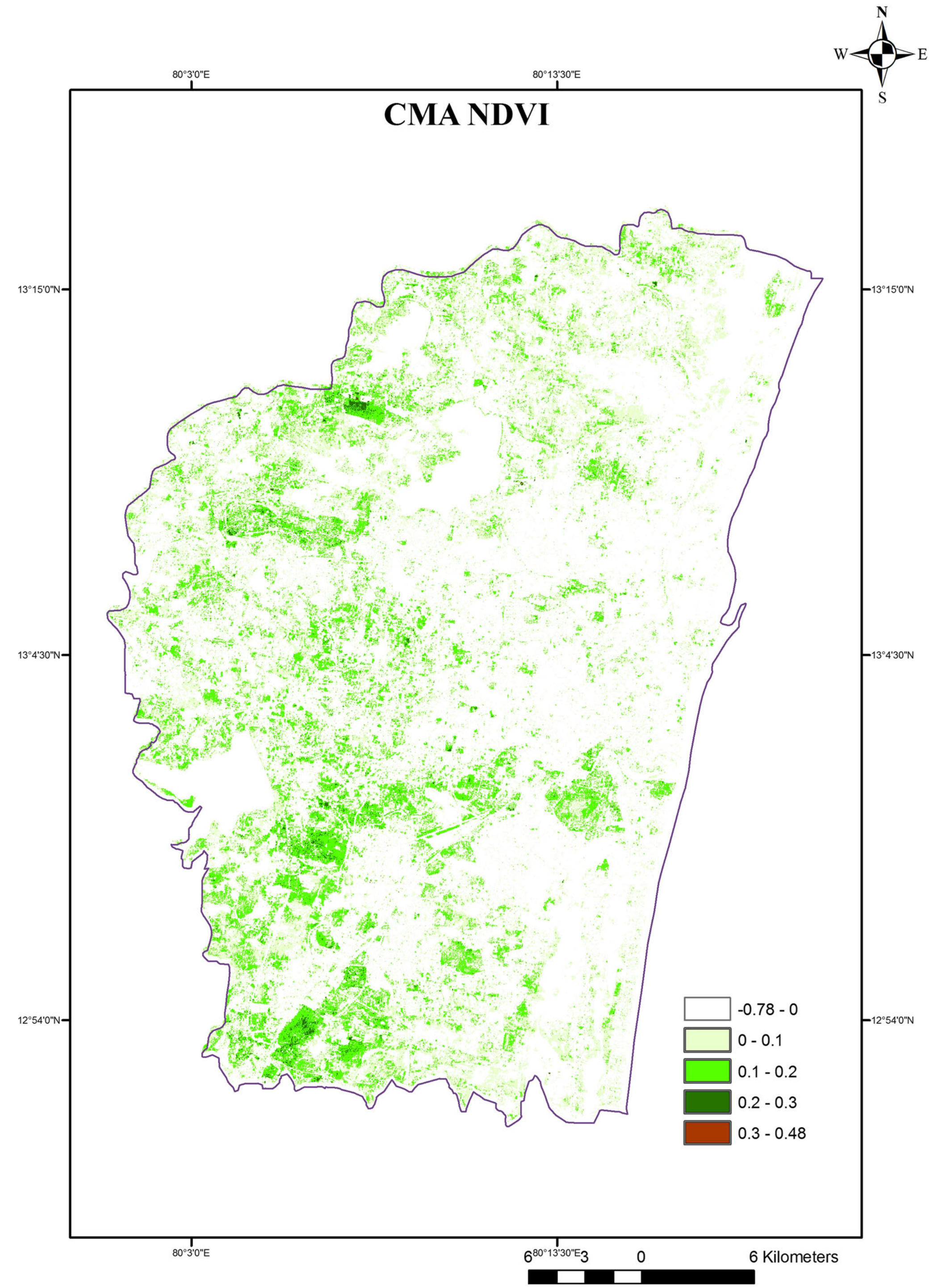

Fig. 7 Normalized Difference Vegetation Index for CMA during May 2012

and indicated a strong negative correlation of NDVI with surface temperature of Delhi.

The cooling rate in densely vegetated areas is fast and can be attributed to evaporation and evapotranspiration, which lower the temperature in green areas (von Stulpnagel et al. 1990). One way to mitigate the UHI effect is by increasing vegetation cover and albedo (Oke 1997). In CMA, the area where a high temperature

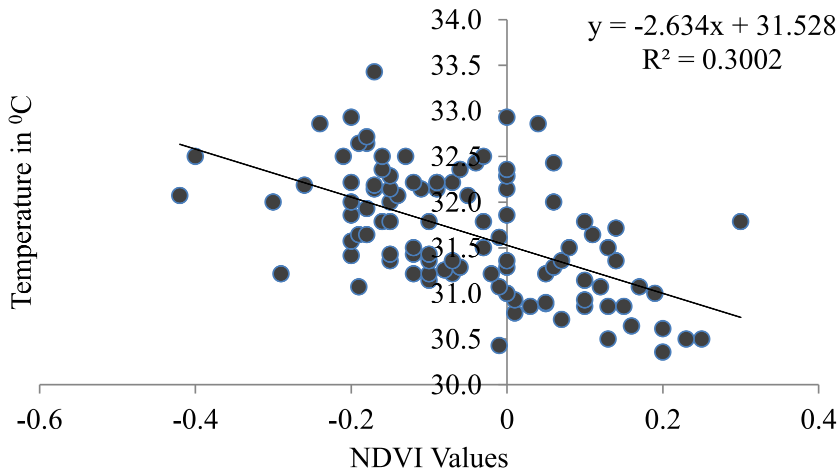

Fig. 8 The correlation between NDVI and observed temperature

observed has less than 1 % of the vegetation cover and the area where low temperature in the range of 29.5–31.5 °C has 64 % of the vegetated area (Fig. 9). There is a significant correlation (r=0.99 p=0.037) between vegetation cover and temperature distributions throughout the city. Similar results were revealed in the study conducted by Yue et al. (2007) in Shangai city, China. Thus, it could be understood that the green cover of CMA influences the temperature and hence the UHI effect.

5 Conclusion

This study has clearly brought out the fact that urban conglomerate and vegetation cover have a serious impact on city's microtemperature. The findings reveal that temperature fluctuation in the city is correlated well with green cover. Vegetation density and land use are playing crucial role in determining the urban climate of CMA. UHI temperature differences were seen in the range of 3–4.5 °C within the city. One important aspect of achieving urban sustainability is strengthening our ability to respond to the changing relation between urbanization and climate. Vegetative cover is a sure way to mitigate this effect as seen in this study. Therefore, more "lung spaces" development of parks and afforestation at strategic local is a sine qua non for mitigative effect. As documented in CMDA II Master Plan (2008), a policy of "green wedges" should be adopted to protect agricultural areas between development corridors; these areas would provide space for not only recreation but also to improve the comfort level in the city. Chennai is a rapidly growing city not only in India but also in the South Asian region with respect to population, area, industrial, and economic activities. As the urban area continues to expand, the scientific knowledge of the urban heat island must be more effectively taken up by architects, engineers, and planners and has to be translated into intelligent climate-proof urban design.

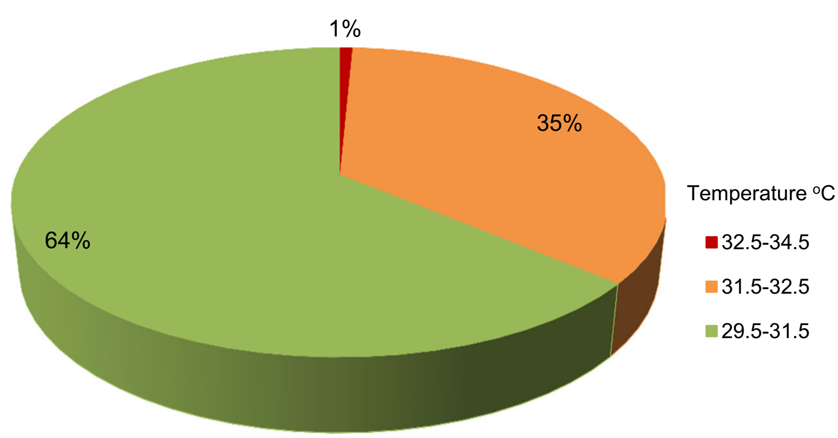

Fig. 9 Relationship between percentage of temperature range and vegetated areas

Acknowledgments The authors are thankful to research scholars at the Centre for Climate Change Adaptation Research, Anna University, Chennai, for their full support during data collection. The authors are also thankful to Dr. N. Jayanthi, formerly Additional Director General of Meteorology, IMD and Dr.S.R. Ramanan, Director, Area Cyclone Warning Centre, RMC, Chennai for their expert opinion and suggestions to this work.

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