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Spatio-temporal analysis of micro-urban heat islands in Greater Hyderabad using remote sensing and GIS

N. Sridhar and Anand Gopagani*, Telangana

Abstract

Micro - Urban Heat Islands (MUHI) are also called intra-urban heat islands or urban hot spots. Micro - Urban Heat Islands (MUHI) are formed due to changes in land use/land cover of urban areas. In this paper, the canopy layer urban heat island (CLUHI), and surface urban heat island (SUHI) were also analyzed along with micro-urban heat islands (MUHI). The identification and Spatio-temporal analysis of the MUHI and CLUHI of Hyderabad was undertaken based on data on air temperature. The identification and analysis of surface urban heat island (SUHI) is done based on land surface temperature (LST) data obtained from thermal remote sensing. Arc GIS is used to map and analyze the micro and canopy layer urban heat islands of Hyderabad. The concentration of micro-urban heat islands / urban hot spots is in the core of the city whereas cool islands are concentrated in the periphery of the city. The magnitude and intensity of micro-urban heat islands changed spatially and seasonally. The temperature difference between the core of the city and the rural surroundings is 4°C - 5°C in the CLUHI. The boundary of the surface urban heat island coincides with the spatial extent of the densely built-up area of the city.

Keywords: *Canopy layer, land surface temperature, urban heat island, thermal remote sensing*

Introduction

Urban heat island (UHI) can be defined as the elevated temperature of urban areas compared to its rural surroundings (Xiao-Ling et.al, 2006). The urban heat island may be classified into three types based on atmospheric and surface temperature: 1. canopy layer urban heat island (CLUHI) 2. boundary layer urban heat island (BLUHI) 3. surface urban heat island (SUHI) (U.S. Environmental Protection Agency 2008). CLUHI is the layer of air closest to the urban land surface or the layer of atmosphere that is in immediate contact with the land surface. It extends approximately to a mean building height. BLUHI is located above the canopy layer which may extend up to 1 km or more height in the daytime and reduce to a few meters at night. Surface heat island (SHI) is related to the temperature of the urban land surface. SHI records higher surface temperatures in urban areas as compared to its surroundings. It can be best illustrated with a Thermal infrared (TIR) image. Surface temperature is observed by thermal infrared data that allows retrieval of land surface temperature. In this study, micro-urban heat islands and canopy layer UHI are identified using air temperature data whereas surface

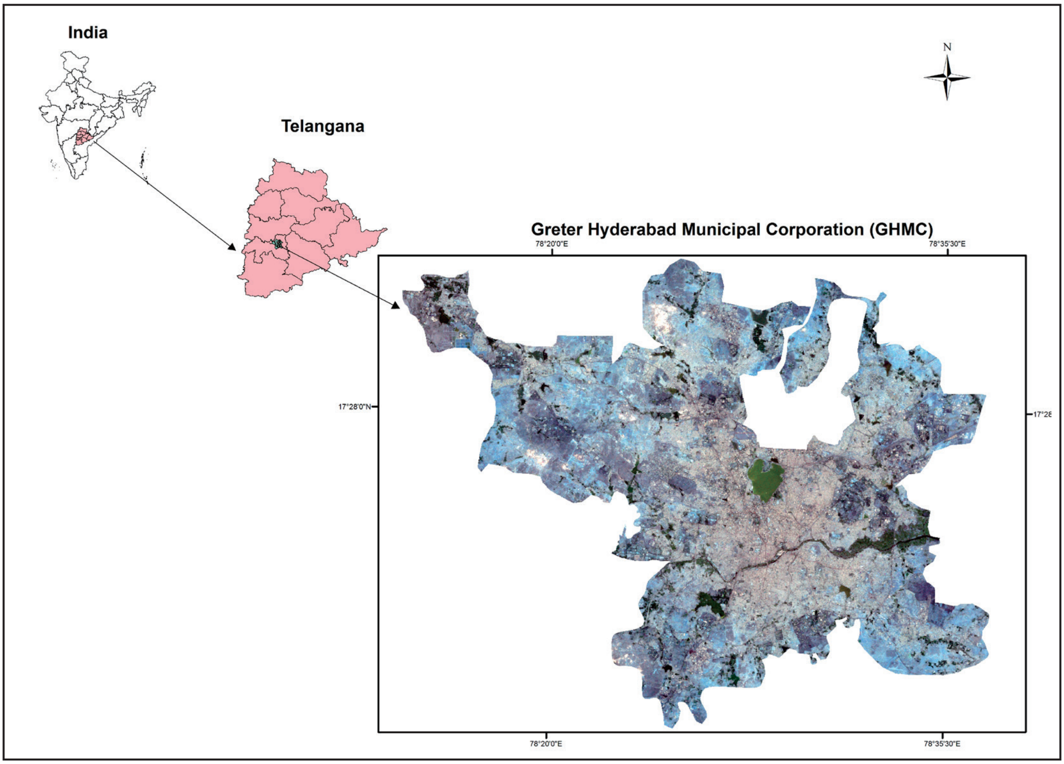

Fig. 1: Location of the study area
Source: GHMC & LANDSAT 8,2013

UHI is identified using thermal data obtained from thermal remote sensing. Micro urban heat islands (MUHI) are also referred to as urban hot spots (Cathy et. al. 1995). Although the urban areas are generally warmer than surrounding suburban and rural areas, the temperature distribution is not a simple urban-rural gradient. Within the city too, there are large temperature differences (Singh et.al, 2014). The consequences of these temperature variations lead to the formation of intra-urban heat islands and cool islands. Urban areas are not homogenous in their land use and surface characteristics and therefore the thermal environment also varies within the city. Intra-urban heat island and Cool Island reflect the localized effect of building density and surface cover (Amirtham, et.al. 2009). MUHI are strongly affected by microclimatic factors. They are also called intra-urban heat islands (Mallick et.al, 2008). Urban heat sink areas are also called negative heat islands or cool islands.

The scale of measure of micro-urban heat islands in this study is within the city limits. The measure of micro-urban heat island is done seasonally. The seasonal average minimum air temperature of particular months is taken as the scale of measurement of MUHI. The canopy layer heat island is mapped based on an annual average minimum air temperature of Greater Hyderabad and its surroundings. The cool and heat islands are mapped on the nighttime air temperature

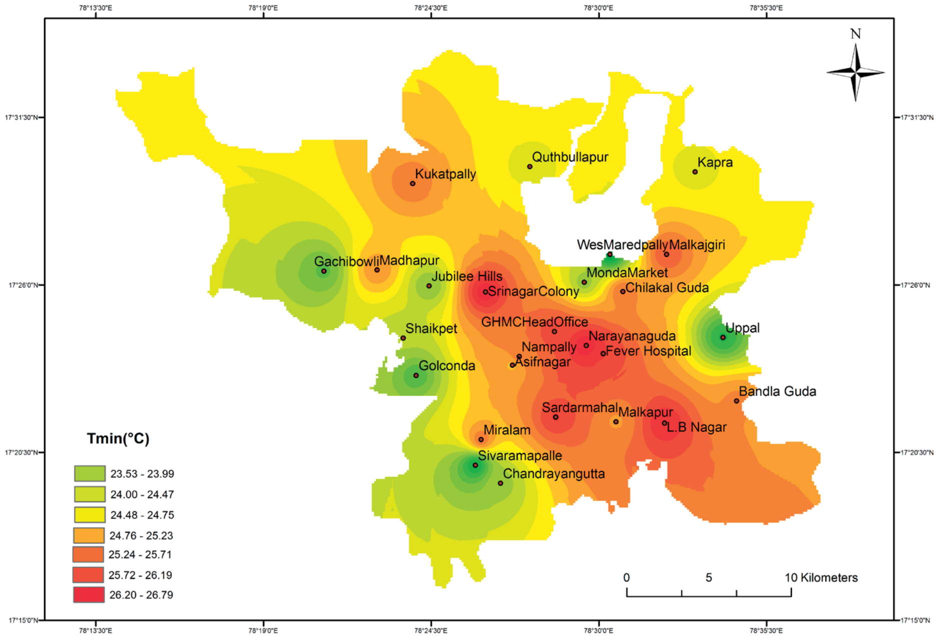

Fig. 2. Spatial distribution of minimum temperature of the summer season – Greater Hyderabad

Source: Interpolated based on AWS data

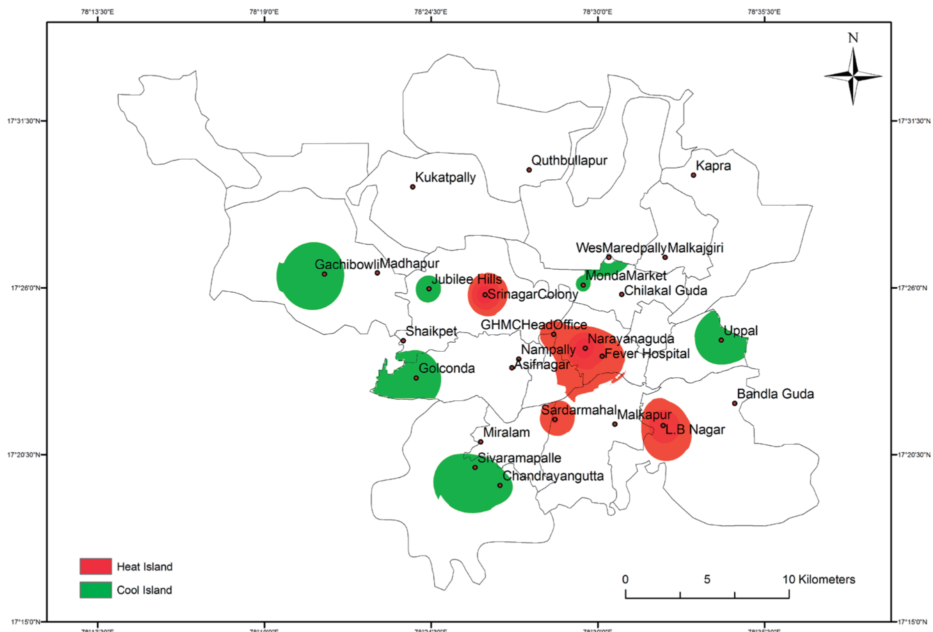

Fig. 3: Spatial distribution of micro-urban heat islands – Greater Hyderabad.

Source: Interpolated based on AWS data or minimum temperature. The surface heat island is identified based on nighttime land surface temperature data from MODIS.

Surface UHI can be identified and measured using thermal remote sensing and it can be present at all times of the day and night. The SUHIs are more intense in the summer daytime. Canopy layer and boundary layer UHIs can be identified based on the temperature data from automatic weather stations (AWS) and it is less present in the daytime but more intense during the night. The study of different urban heat islands would help study the impacts of UHI at the micro level. The impacts of UHI can be measured and evaluated by studying different UHI (i.e. MUHI, CLHI, BLUI, and SUHI). The negative impacts of UHI like increasing emission of air pollutants and greenhouse gases and increased energy consumption can be understood in depth by analysing different types of UHIs (U.S. Environmental Protection Agency 2008). The intra-urban variation of land surface temperature is closely related to land use/land cover. The densely built-up areas record more temperature as compared to vegetative cover areas (Jiang and Tian. 2010). The study of urban heat islands is helpful in identifying the changing urban meteorology conditions like urban wind patterns, humidity, clouds, and fog formation. Total annual precipitation is increased in some cities, especially in the mid/high latitudes and tropics, and decreased in other cities, especially in the subtropics (Blake *et al*, 2011). The land surface temperature is the controlling parameter for the air temperature (Katpatal *et al* 2008). UHI effect will influence the regional climate, environment, and socio-economic development (Chen, 2006). Heat-related health illness can also be minimized by identifying and formulating methods to minimize the effects of urban heat island. The main objectives of the study are to identify surface urban heat island, map the canopy layer heat island, and study the spatiotemporal (seasonal) variation of micro-urban heat islands.

Study area

Hyderabad is the capital of Telangana State. The city is located at 170 36' north latitude and 780 47’ east longitude. The location of greater Hyderabad is shown in Fig. 1. April 2007 onwards, the municipal corporation of Hyderabad became Greater Hyderabad Municipal Corporation (GHMC) by merging neighbouring municipalities. This increased the area of Hyderabad from 175 km^2 (1996) to 650 km^2 in 2007(GHMC, 2007). The decadal growth of the population of Hyderabad is 87 percent (Census of India, 2011). The spatial and demographic growth of Hyderabad has increased the pressure on the urban environment of the city. The loss of water bodies, and vegetative cover along with increasing levels of air pollution and emission of greenhouse gases, are factors that have contributed to the change of surface as well as air temperature of the city. Today, with the rapid phase of urbanization and industrialization, there is increasing pressure on land. Hyderabad has also emerged as an important Information Technology (IT) hub; business, educational, and cultural destination too. These rapid changes have resulted in alarming growth in built-up areas, loss of agricultural land, water bodies, and vegetative cover along with increasing levels of air pollution, suspended particulate matter, and emission of greenhouse gases. Between 2001 and 2011, the population of Hyderabad increased by 87 percent with the addition of over 3.1 million people to its ever-growing population. The population has increased from 3,637,483 in the 2001 Census to 6,809,970 in the 2011 Census. A majority of this increase is on account of the excessive flow of migrants from other parts of India into Hyderabad. The migrant population constitutes nearly a fourth (24%) of the total city population.

Database and Methodology

Temperature (air) data was obtained from automatic weather stations in point data from Greater Hyderabad Municipal Corporation for the year 2013. ArcGIS spatial interpolation technique was used to show the spatial distribution of temperature and identify the micro-urban heat and cool islands. Land surface temperature data was obtained from the moderate-resolution imaging spectroradiometer (MODIS) thermal band nighttime imagery. Land Surface Temperature was extracted from MODIS thermal band image using a split-window LST algorithm developed by Zhengming Wan for retrieving land surface temperature (LST) from MODIS data (Wan, 1996). A land use/Land cover map was prepared using Landsat 8 data of 2013.

Results

Summer season micro-urban heat islands

Urban Heat Island (UHI) is an elevated temperature in urban areas compared to its rural surroundings. This temperature difference is usually larger at night (minimum temperature) than during the day (maximum temperature). A cursory glance at figure 2 revealed that the entire GHMC, except a few locations (Gachibowli, Uppal, Bandal Guda), recorded higher temperatures of more than 25 °C leading to an extensive warmer surface with the emergence of numerous micro-urban heat islands.

The spatial pattern of micro-urban heat islands shows their concentration in the central part of the city around GHMC Head office, Narayanguda, Fever Hospital, and Sardarmahal. These heat islands coalesce to form an extensive area of heat islands in the central part of the city. From the heat island in the central part, the higher temperature areas extended in the northwest and northeast direction to form Srinagar Colony and Malkajgiri heat islands.

In the eastern part of the urban periphery, the heat islands emerged around Uppal and West Maredpally in the north-central part of the city. The highest temperature (26.79°C) is recorded in the heat island located in the central part of the city and least temperature of the heat sink area is around 23.54°C (Fig. 3). The urban heat sinks are mostly concentrated in the western part centered on Gachibowli, Jubilee Hills in the north-west, Shivarampally and Chandrayanagutta in the southwest, and to a lesser extent around Shaikpet and Golconda area in the west, due to the presence of vegetative cover and less built-up area (Fig. 4). The variation of intra-urban temperature minimum (Tmin) during the summer season is 3.26 °C.

Winter season micro urban islands

During the winter season, the minimum temperature (Fig. 5) in the study area is higher in the central part of the city covering the Municipal Corporation of Hyderabad (MCH). Peripheral areas recorded relatively lower temperatures as compared to the core of the city. Micro urban heat sinks conspicuously developed in the western periphery around Gachibowli and to a lesser extent around

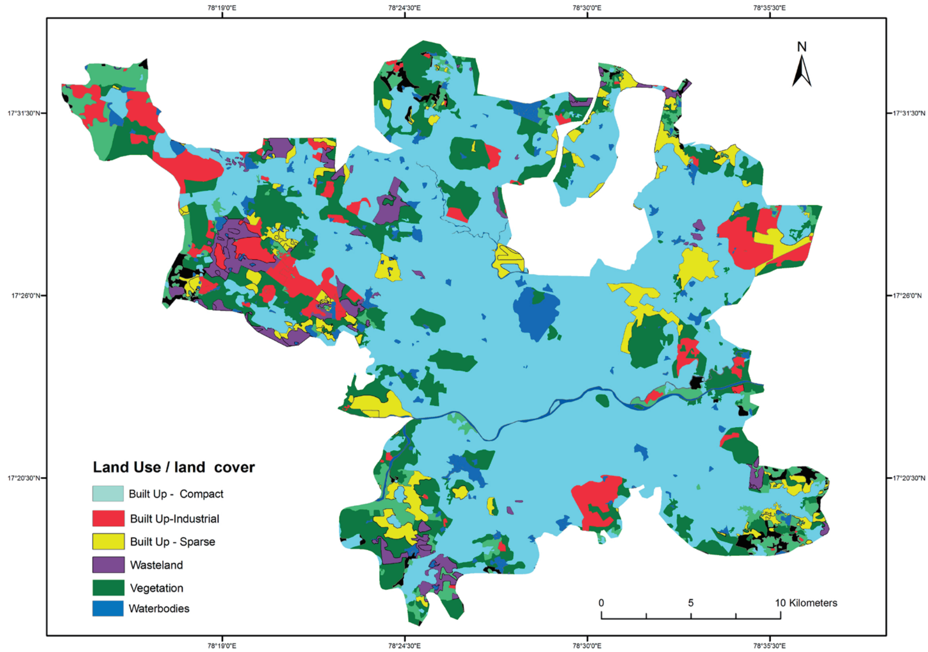

Fig. 4: Land use/land cover – Greater Hyderabad.

Source: LANDSAT 8, 2013.

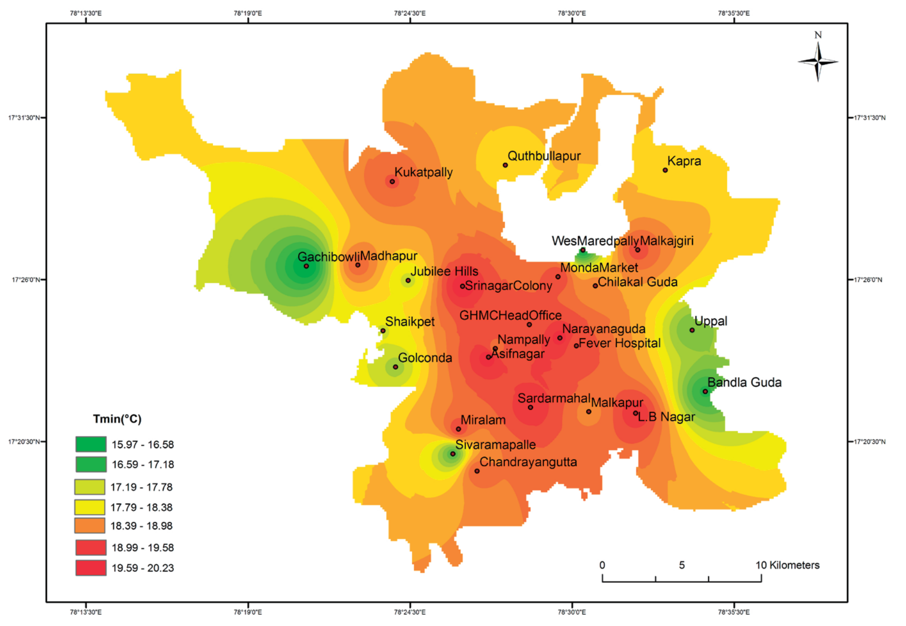

Fig. 5: Spatial distribution of minimum temperature in winter season – Greater Hyderabad

Source: Interpolated based on AWS data.

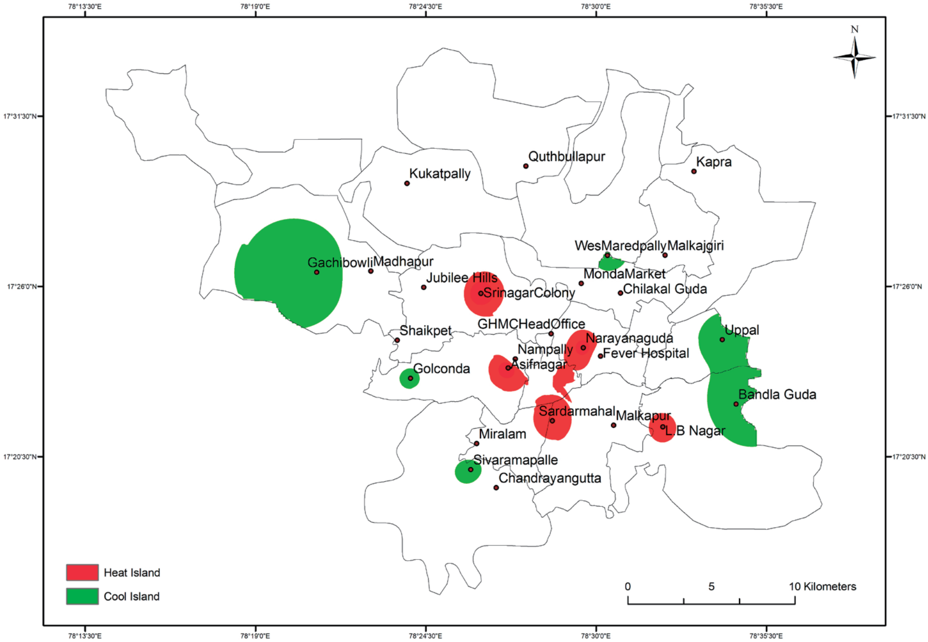

Fig. 6: Spatial distribution of micro-urban heat islands – Greater Hyderabad.
Source: Interpolated based on AWS data

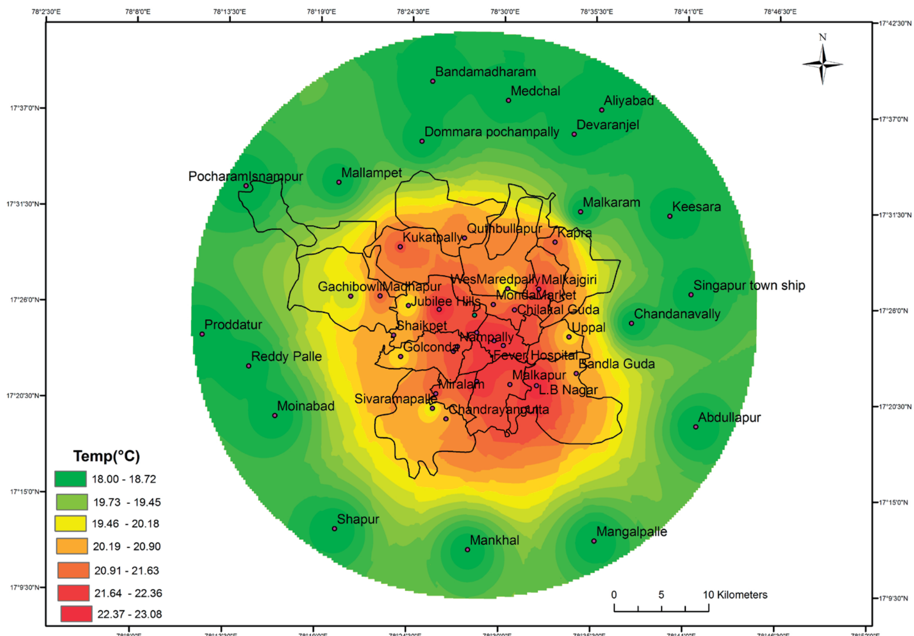

Fig. 7: Spatial distribution of canopy layer urban heat island – Greater Hyderabad.
Source: Interpolated based on AWS data

Shivarampally (Fig. 6). In the eastern periphery, elongated cooler areas are found in the north-south direction with cool islands centered around Uppal and Bandlaguda. A very small urban heat sink is seen around West Maredpallly. On the whole, the extensiveness and spatial diffusion of urban heat island in the central part of the city are clearly visible in the distribution pattern of Tmin in the winter season. The variation in temperature between urban heat island and cool islands is around 4.26°C. Chandrayangutta, Gachibowli, Jubilee Hills, Shivarampally, and Uppal have emerged as heat sinks or cool island areas throughout the year.

Based on the spatial analysis of microclimate and consequent formation of heat islands and heat sinks, it is seen that temperature within urban areas does not follow a simple gradient or zoning i.e. a zone of higher temperature in the inner city and lower temperature in the fringe, but it is rather more complex.

There is no single heat island within the city but a number of them are interspersed with areas of low temperature or cool islands. But in general, the heat islands areas are present as islands in the central part of the city whereas isolated cool islands are formed especially in the western periphery. Further, the location of intra-urban heat and cool islands changes seasonally and spatially. The core of the city, the CBD, is warmer but the concentric temperature gradient pattern from the urban core to the periphery is not clearly visible. The reason for the emergence of isolated pockets of heat and cool islands is due to the fact that urban areas are rarely homogenous in their land use and other surface characteristics and therefore, the thermal environment also revealed micro variation resulting in cellular isolated heat and cool islands.

Canopy layer urban heat island

The canopy layer urban heat island is the layer of air closest to the urban land surface or the layer of the atmosphere that is in immediate contact with the land surface. It extends approximately to a mean building height. Canopy layer Heat Island intensity is the maximum at night. These heat islands provide some possible understanding of heat transfer from the surface to the canopy of urban areas. A canopy layer heat island study could be more appropriate for evaluating urban heat storage. It is quantified by air temperature data obtained from urban and rural weather stations.

Identification of the canopy layer heat island is based on the annual air temperature for the year 2013. Temperature data is obtained through AWS located within the urban areas as well from as those located in rural surroundings (i.e. 30 km radius from the city center). Based on air temperature, the canopy layer heat island is mapped as shown in figure 7. The formation of an urban heat island depends on certain weather conditions like clear sky, calm atmospheric conditions, and low wind speed. It is seen from figure 7 that the core of the city recorded higher temperatures (27.5°C). The spatial extent of the canopy layer UHI coincides with the spatial extent of densely built-up and populated areas of the city. The radius of the urban heat island extends for about 15 km from the city center.

The intensity of urban heat island is the magnitude of heat island which denotes the temperature variation in the city relative to its rural surroundings. The temperature recorded in the core of the city is about 27.50°C which gradually decreases towards the periphery. The temperature recorded at the urban periphery is around 25°C. This zone acts as high high-temperature cliff showing a transition between urban and rural surroundings. Urban-rural temperature variations at this boundary will be higher.

The spatial or horizontal structure of the urban heat island therefore is characterized by a steep temperature gradient that is seen at the urban periphery which is indicated by the yellow colour in figure 7. The temperature of the urban core is around 27.5°C whereas the temperature of rural surroundings is about 23°C. Therefore, the intensity of the canopy layer urban heat island (i.e. urban-rural boundary heat island) is around 4.5°C.

Surface urban heat island

The surface heat island is identified based on a Moderate-resolution Imaging Spectroradiometer (MODIS) thermal band with a spectral range between 11.770 - 12.270 um. The nighttime imagery for 15 December 2013 is used. The DN or grey values obtained through the imagery were converted to surface temperature. The spatial resolution of the thermal band is 1 km which is a very coarse resolution. Surface urban heat island is based on land surface temperature retrieved from the nighttime MODIS thermal band. The extent of the surface urban heat island, as emerged based on land surface temperature, is depicted with the help of red colour (Fig. 8). The surface heat island as emerged is associated with the densely built-up urban area. The finer thermal variation/gradient could not be recorded from land surface temperature derived from MODIS due to the coarse resolution of the thermal image.

The structure of an urban heat island based on LST reveals its less extensive spread as compared to a canopy layer heat island. As seen in figure 8, there is a decrease in temperature from the core of the urban area towards the rural surroundings. The spatial extent of the surface heat island is around 10 km. Its extent is slightly more towards the north, especially in the northwest and northeast directions. The extension of the urban heat island to some extent is also in the southeastern direction along the Vijayawada highway. The spatial demarcation of the urban heat island can be visualized with the help of red color as seen in figure 8. The immediate rural surroundings have shown a decline in temperature as compared to the core of the city which is associated with yellow color. This zone extends from the outer limit of the surface urban heat island up to a distance of about 8 – 10 km. Within this zone, there are pockets of high and low surface heat islands. The outer zone is characterized by low temperatures associated with rural areas.

It is seen from figure 8 that the outer low-temperature zone associated with rural areas is not very distinct and continuous. The low-temperature areas are conspicuous in the western, northern, and southern parts with pockets of warm areas whereas the eastern margin of the rural belt is much warmer. The study could not go deeper to explain these variations in the temperature especially in the rural surroundings. The intensity of the surface urban heat island is about 12°C. The study highlights the identification of urban heat island based on land surface temperature

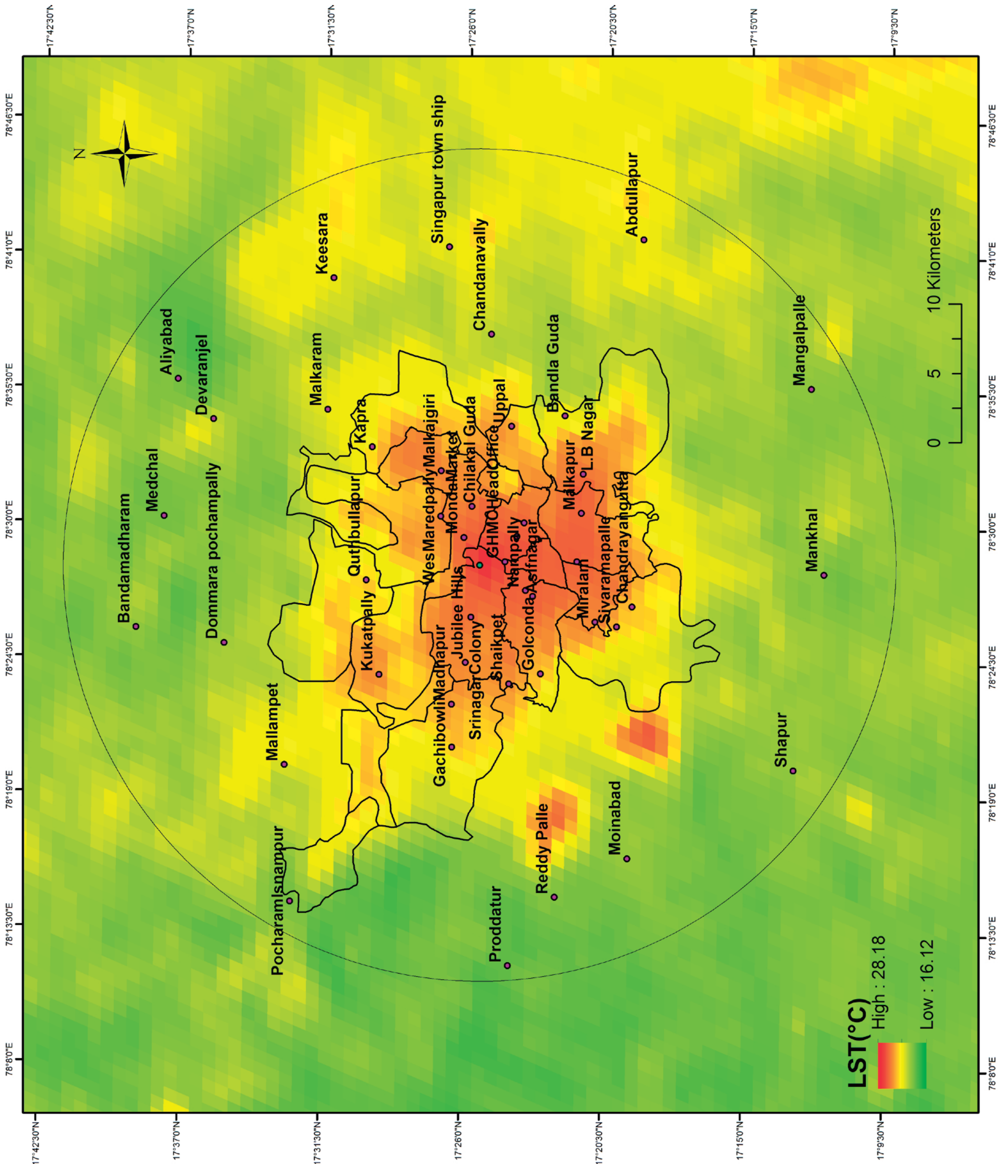

Fig. 8: Spatial distribution of surface urban heat island – Greater Hyderabad.
Source: MODIS, Thermal Band Image

which varies seasonally. Hence, the spatial extent of urban heat island also varies. Here, only the land surface temperature of December month is taken into consideration for the identification of surface urban heat island. Therefore, the boundaries of the canopy layer heat island and surface heat island are not similar in nature.

Conclusion

As evident from the study, canopy layer micro-urban heat islands as well as cool islands emerged due to urban micro-climatic variations. The reason for the emergence of isolated pockets of urban heat and cool islands is due to the fact that urban areas consist of non-homogenous land surfaces. Intra-urban heat and cool islands are identified based on the highest and least temperatures recorded in the study area. Seasonal and spatial analysis of intra-urban heat islands revealed that there are few locations that emerged as micro-heat islands in all the seasons. The heat islands are mostly associated with the central part of the city; whereas cool islands are located in the western periphery of the city. The canopy layer urban heat island is more or less confined to the Greater Hyderabad Municipal Corporation (GHMC) limit. The variation of temperature between urban core and rural surroundings is up to 4.5°C. The surface heat island is clearly linked to the densely built-up areas. The intensity of the surface heat island is about 12°C. The impact of urban heat island revealed that the intensity of rainfall is with thunderstorm activity as is commonly associated with urban heat islands. The other impact is the formation of pollution domes, heat waves, etc. Due to urban heat island effects, Hyderabad city is experiencing a gradual shift in its local climate pattern. The city is experiencing the heaviest rainfall in recent years. The frequency of high-intensity rainfall causing floods in the city is increasing and will continue to increase. In the coming years, the frequency of sudden downpours and intensity may increase sharply.

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N. Sridhar
Post Doctoral Fellow
Department of Geography,
Osmania University, Hyderabad

Anand Gopagani*
Assistant Professor
Department of Geography,
Osmania University, Hyderabad

*Author for correspondence
E-mail: anandgopagoni@gmail.com