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A STUDY OF TEMPORAL CHANGE IN LAND SURFACE TEMPERATURE AND URBAN HEAT ISLAND EFFECT IN PATNA MUNICIPAL CORPORATION OVER A PERIOD OF 25 YEARS (1989 – 2014) USING REMOTE SENSING AND GIS TECHNIQUE

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Abstract

It has become a fact which has been proved many times with scientific data that with the increase in urbanization the natural environment is negatively affected resulting in change in the micro climate of the given area. The variations in Land Surface Temperature (LST) with in a Municipal area are of highest concern to the study the urban climate and human-environment interactions. The present study investigates the temporal change in surface temperature of Patna Municipal Corporation (PMC) using Remote sensing data. For this purpose radiometric and geometric correction of the satellite data was done, further estimation of surface temperature was done using the required Band math for different Satellite sensors and finally spatiotemporal model and statistical techniques were used to determine the variations in Urban Heat Island (UHI) effect in Patna Municipal Corporation (PMC). The results were proportional to the assumptions, the dense built up and commercial / Residential areas show higher surface temperature in comparison with adjoining areas while the Urban Greens (vegetations) were the cooler part of the Municipal area.

Key words: Urbanization, Land Surface Temperature (LST), Satellite Data, Urban Heat Island (UHI), Urban Greens.

Introduction

The Municipal areas are dynamic in nature and because of anthropogenic activities, population growth and urbanization they change time to time altering the Land use Land cover (LULC). Zhanq and Wang (2008) studied the inter relationship between these issues and found that there is a correlation between the formation of the heat island, population density and concentration of built [1]. With the increase in urbanization the vegetated surface of an area is converted into impervious surface resulting in change pattern in absorption of solar radiation, storage of heat, surface temperature, evaporation rate, wind turbulence thus negatively affecting the micro climate of the area [2].

Land surface temperature can provide important information about the surface physical properties and climate which plays a role in many environmental processes [3] [4]. Many studies have estimated the relative warmth of cities by measuring the air temperature, using land based observation stations. The land observation based method can be both expensive and time consuming and lead to problems in spatial interpolation. Remote sensing might be an alternative to the aforesaid methods. The advantages of using remotely sensed data are the availability of high resolution, consistent and repetitive coverage and capability of measurements of earth surface conditions [5]. A large number of researches have been done using remotely sensed data to detect thermal characteristics of urban surfaces. Voogt and Oke (2003) reviewed the use of thermal remote sensing for the study of urban climates with respect to the heat islands and described the distinction between the atmospheric and the surface UHIs [6].

However both the methods including ground based meteorological observation and satellite observation (Remote Sensing data) for Land Surface Temperature estimation have their own positive and negatives. The former has the advantage of analyzing directly the differences in temperatures between urban and suburban areas, but because of the discrete distribution and limited numbers of observation stations, it has shortcomings in large-scale studies. Remote sensing, on the other hand, is useful for analysis of regional-scale characteristic because of the continuity of observations, and it is widely used in every scale of research. When remote sensing is used, land-surface temperature is usually retrieved through a mono-window algorithm, a thermal radiance transfer equation, and an image-based inversion algorithm based on thermal infrared data. The latter algorithm is relatively simple, and it can be used to study the dynamic changes of the thermal fields. However, the best method for delimiting UHIs is still uncertain [7]

Study Area

Patna is one of the oldest continuously inhabited places in the world and Patna Municipal Corporation (PMC) is located between Latitude: 25°33'10"- 25°39'03" North and

Longitude: 85°03'16"- 85°16'10" East, it lies on the south bank of the River Ganges. PMC is approximately 21.5 km long (east to west) and 11 km wide (north to south). The corporation area is important commercial centre. The commercial establishments within the city are mainly lined along the arterial and major roads and there is extensive mixed land use of commercial and residential use throughout the city.

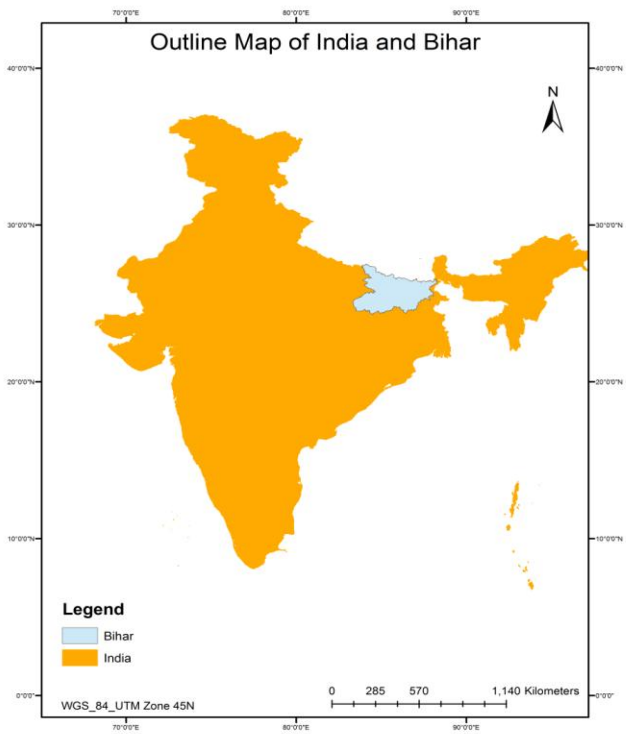

Fig. 1(a) Outline Map of India and Bihar

The natural growth of PMC has been towards the west till date, with the older part of it being in the east side of the city [8]. This core area of PMC faces problems of overcrowding, which has lead to enormous pressure on the physical infrastructure and traffic congestion. The newer developed areas lying in the central and western part of PMC comprises of both plotted developments and apartment houses. The apartments in the newly developed area are again straining on the existing infrastructure, as the up gradation of the physical infrastructure has not been done in proportion to the increase in population being accommodated in the apartments.

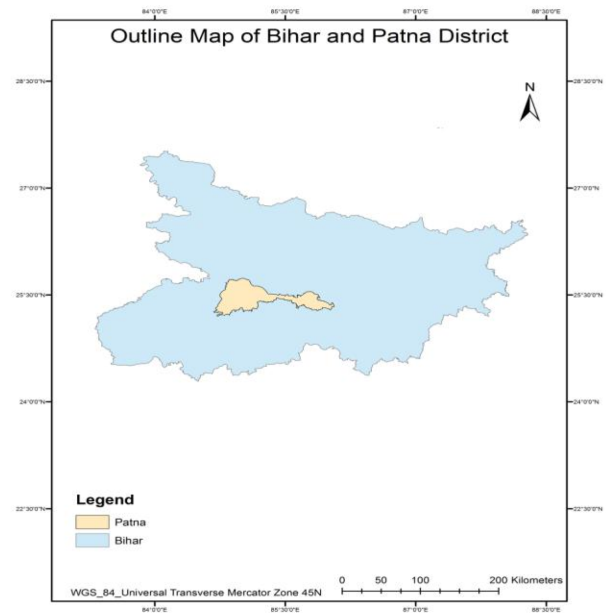

Fig. 1(b) Outline Map of Bihar and Patna District

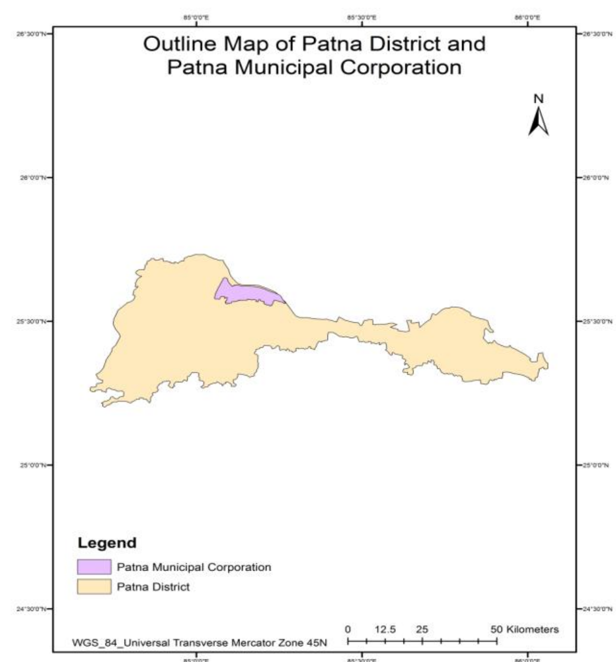

Fig. 1(c) Outline Map of Patna District and PMC

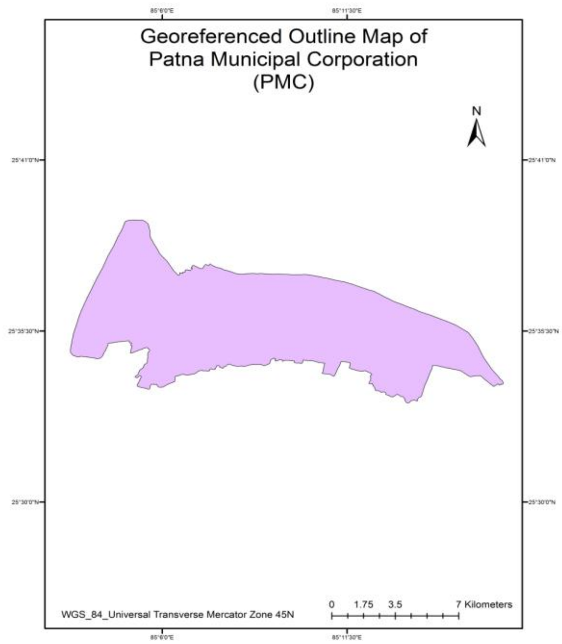

Fig. 1(d) Outline Map of Patna Municipal Corporation

The Patna Municipal Corporation (PMC) covers an area of nearly 108.164 km^2 according to our Remote Sensing and georeferencing results. It is further divided into 72 wards. According to the 2011 census it had a total population of 16, 83,200. The density of population of the PMC is 15562 persons per km^2. The trends of population growth have been uneven in the period 1951-2011. The growth registered an increasing trend in the period 1961 to 1981 - from 28.52% to 64.14%. It reduced to 18.14% during 1981 to 1991, rising again in 1991 to 2001 to 48.97% and dropping again during 2001 to 2011 to 32.53% [9].

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Objectives

- The main objective of this study is to study the temporal change of Land Surface Temperature (LST) of Patna Municipal Corporation in last quarter century with the help of Thermal Infrared Satellite data.
- To determine the average increase in LST in last 25 years (1989-2014).
- To assess the Urban Heat Island (UHI) effect in Patna Municipal Corporation (PMC).

Dataset and Method

Google Earth data for the present year (2014) and Survey of India latest Toposheet G45N2 and G45N6 are used. PMC map* with 72 wards is used. (*Base MAP of PMC is as per 2001 Administrative command, the same base map and boundary is used by Department for International Development (DFID) UK for its developmental plans for Bihar with collaboration with the provincial government).

A discrete georeferenced map of Patna Municipal Corporation is prepared from scratch with all the required parameters. KML file was created in Google Earth Pro with the help of Polygon tool according to reference base map of PMC with 72 wards. For georeferencing and shapefile conversion GRgarmin along with ISRO's Bhuvan were used and required ground truthing was done.

Table-1: Details of satellite data

Satellite	Sensors	Date	Resolution	Band	P/R
Landsat - 4	TM	24/01/1989	Re sampled at 30.0 m	6	141/42
Landsat - 4	TM	04/02/1993	Re sampled at 30.0 m	6	141/42
Landsat - 7	ETM+	16/02/2003	Re sampled at 30.0 m	6	141/42
Landsat - 5	TM	13/02/2005	Re sampled at 30.0 m	6	141/42
Landsat - 5	TM	11/02/2010	Re sampled at 30.0 m	6	141/42
Landsat - 8	TIRS	06/02/2014	Re sampled at 30.0 m	10	141/42

This study is mainly based on satellite data. The Thermal Infrared band of Landsat – 4, 5 TM, Landsat – 7 ETM+ and latest in this series Landsat – 8 TIRS have been used. Some precautions were taken in selecting the Satellite image. Cloud free images of same season (Late January and early February) were used for minimum error. All the satellite images were acquired from United States Geological Surveys (USGS) website. Landsat acquired images for Land Surface Temperature is in DNs (0-255), which can be converted into Celsius after processing. The first step is to convert the Digital Numbers (DNs) to radiance value. For this purpose we need to get the bias and gain values. For getting this value Band 6 of Landsat 4, 5, 7 TM/ETM+ and Band 10 of Landsat – 8 TIRS were used. The following formulas were used to calculate the bias and gain for each Landsat scene. For this purpose ENVI 5.1 was used.

$$\text{Bias} = \text{LMIN} \quad (1)$$

$$Gain = (LMAX - LMIN) / (QCALMAX – QCALMIN) \quad (2)$$

The formula for converting the DN to radiance is:

$$P_R = G (P_{DN}) + B \quad (3)$$

Where:

P_R = Pixel radiance value
P_{DN} = Pixel digital number
B = Bias (Offset)
G = Gain

After getting the radiance value it should be converted to the Kelvin with the help of following formula

$$T_k = K_2 / \ln[K_1 / P_R + 1] \quad (4)$$

Where:

T_k = Temperature in Kelvin
P_R = Pixel radiance value

The value of K_1, K_2 is different for TM, ETM+ and TIRS satellite sensors which are shown in Table – 2.

Table-2: Details of K_1, K_2 for Satellite Sensors that were used

	Landsat - 4, 5 TM	Landsat - 7 ETM+	Landsat - 8 TIRS
K_1	607.76	666.09	774.89
K_2	1260.56	1282.71	1321.08

And finally after getting the values in Kelvin, subtracting the value of 273.15 by simple band math the final value can be obtained in Degree Celsius.

$$T_c = T_k – 273.15 \quad (5)$$

Where:

T_c = Temperature in Celsius

After finishing the above mentioned band math and getting the final result in degree Celsius the Landsat tile for each base year were brought in ArcMap for further processing. The area of interest (Patna Municipal Corporation) was clipped and classified into five classes according to the natural breaks in different thermal regions of the area. And lastly Maximum Likelihood Classification was done for all the base years for getting the required data for the statistical analysis.

Table-3: Details of Software used in study

Software Used	Functions
Google Earth Professional 7.1.1	For overlaying RAW map and creating Polygon generated outline KML file
DNR Garmin 5.04	Converting KML file to Shape file , Ground Truthing and Georeferencing
ISRO Bhuvan	Evaluation of shapefile and georeferenced data
ENVI 5.1	Processing of Thermal Landsat tile to Degree Celsius
ArcMap 10.1	AOI clipping, ML Classification and LST/UHI Model Creation
MS Excel 2007	Graphs and Charts

Results and Discussions

The main objective of this study was to determine the value of temporal change in Land Surface Temperature (LST) over the years in Patna Municipal Corporation. Six base years were selected depending on the availability of Satellite data with minimum cloud coverage for the maximum accuracy. All the data were of the same period for minimizing the effect of seasonal change on Land Surface.

The processed satellite data converted into Degree Celsius were classified into five classes e.g.: - Very Low, Low, Medium, High and Very High based on the natural breaks generated in ArcMap. The minimum temperature which was 19.584°C on 4th February 1993 has increased gradually to 22.055°C on 6th February 2014. The increase in minimum temperature is nearly 2.471°C. Similarly there is a big change in maximum temperature too. The maximum LST found the same date in 1993 was 27.284°C which was increased by 3.134°C to 30.418°C. The area under five different temperature classes (based on natural breaks) also changed over the years. It was found that on 24th January 1989 the area under very low and low temperature (19.584°C – 22.356°C) were jointly 56.841 km^2 which calculates to 52.55% of the total study area (PMC). On 16th February 2003 it was reduced to only 22.756 km^2 which was merely 21% of the whole Patna Municipal Corporation area. Again on 6th February 2014 the area under very low and low temperature (22.055 – 24.646°C/based on natural break) increased to 43.895 km^2 which is 40.581% of the PMC. The base year wise LST/UHI model can be found below from Figure 2 (a) to 2 (f).

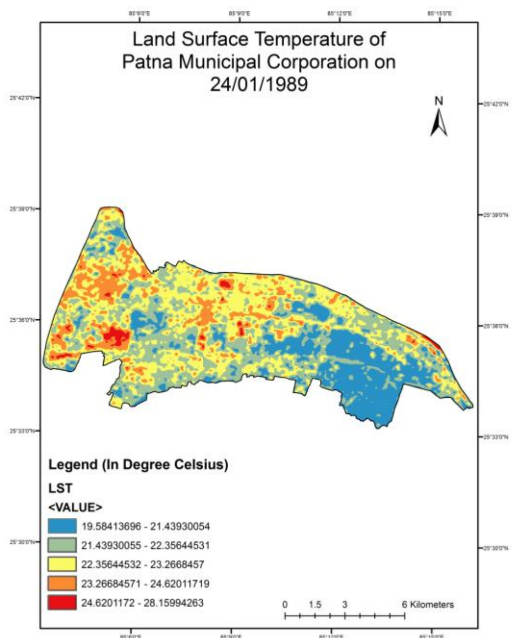


Figure 2(a). LST/UHI Model of PMC on 24/01/1989

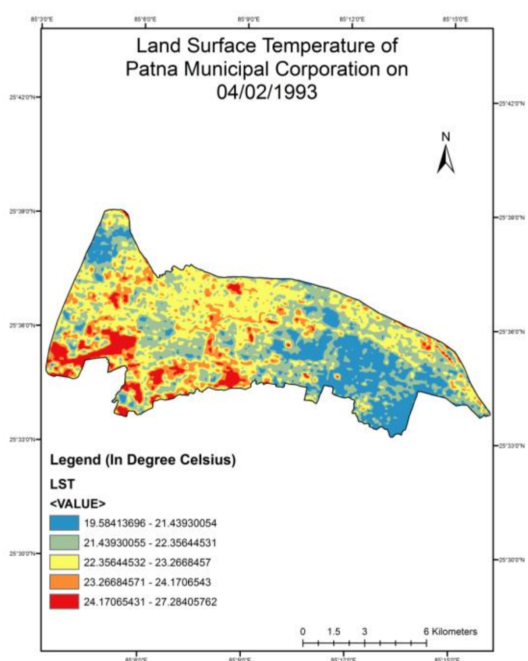


Figure 2(b). LST/UHI Model of PMC on 04/02/1993

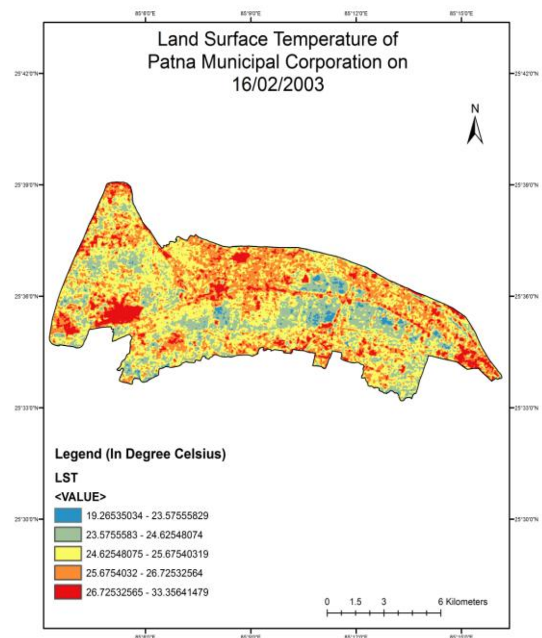


Figure 2(c). LST/UHI Model of PMC on 16/02/2003

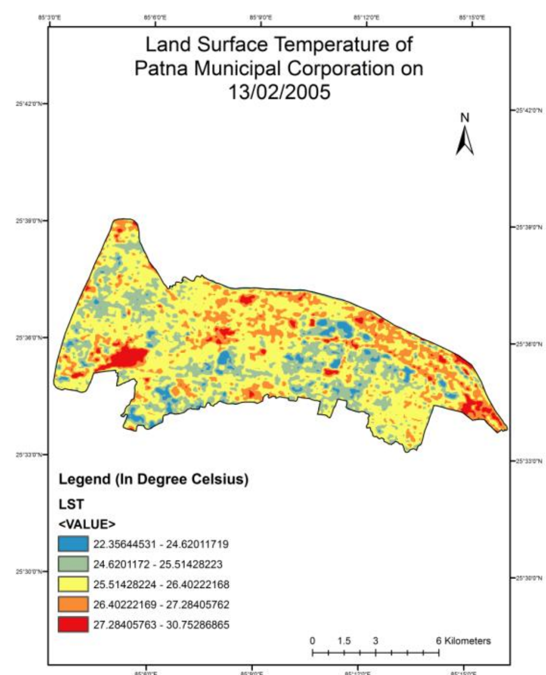


Figure 2(d). LST/UHI Model of PMC on 13/02/2005

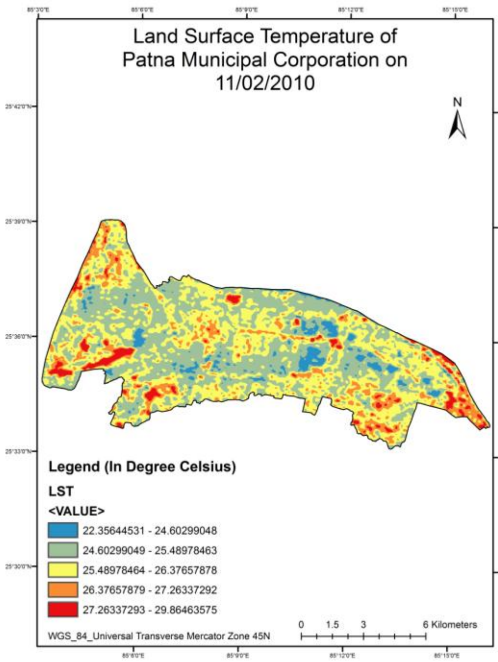


Figure 2(e). LST/UHI Model of PMC on 11/02/2010

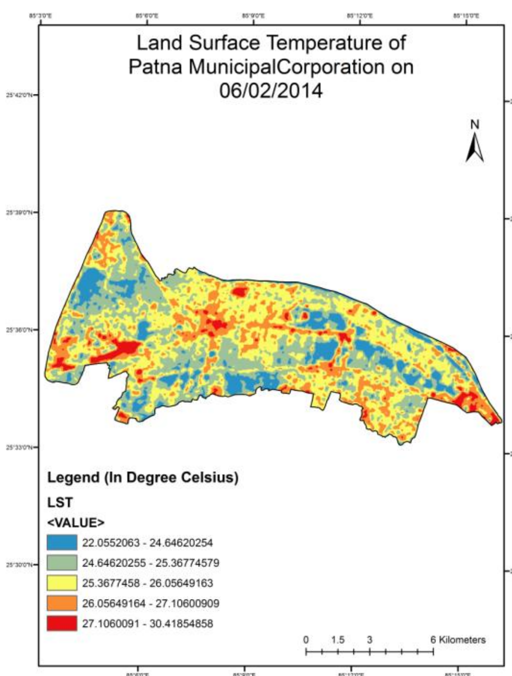
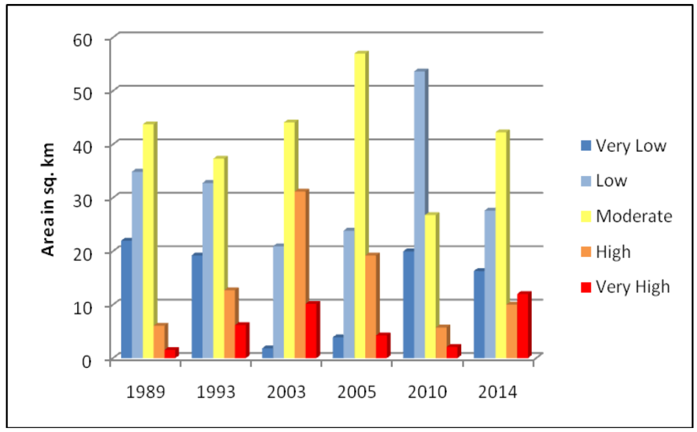


Figure 2(f). LST/UHI Model of PMC on 06/02/2014

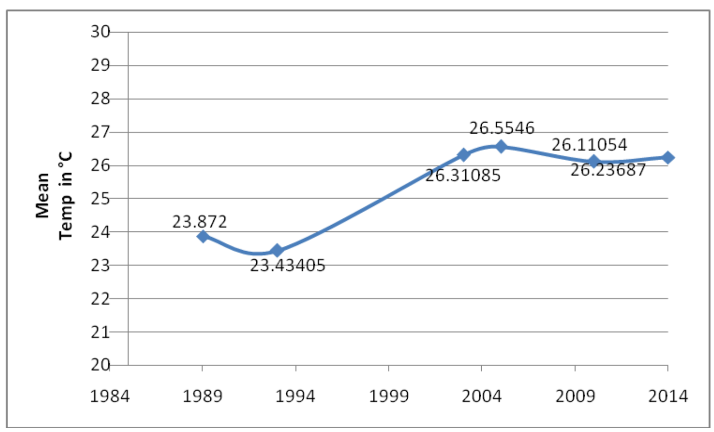
It is observed by the current LST model that those places which are Urban Greens and come under vegetative areas are cooler places which are shown in deep and light sky blue shades while the concrete structure is the warmest part shown in dark to light red color. For example in every base year the runway of Patna airport which is situated in south – west part of the PMC is under Very high to high temperature class which is visible in nearly linear red stripe in every figure 2(a – f). Similarly Patna Zoological and Botanical Garden which is situated on the north east corner of the airport runway is always found to be cooler place shown in figures in sky blue.

The change in LST area is shown below in Graph – 1



Graph-1: Base year wise change in LST / UHI area

It is also noticeable that the mean temperature increased considerably between 1993 and 2003. In 1993 the mean temperature was 23.43°C which increased nearly 3°C to 26.31°C in 2003. Comparing this decadal data with 2014 it can be inferred that the main increase in LST of PMC happened in 1993 – 2003.



Graph-2: Base year wise Mean Land Surface Temperature

The relationship with mean Land Surface Temperature increase with time is shown in figure 3.

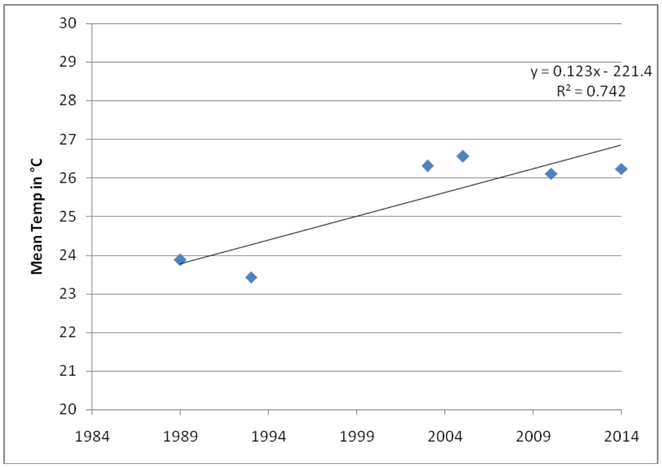


Figure 3 Correlation of Land Surface Temperature increase with Time

Conclusion

A strong correlation between LST and Urban Heat Island effect increase with Time is found (R^2 = 0.742) with the present analysis of data which was the prime objective of the present study. The average increase in LST was also successfully obtained for the last quarter century which is found to be more than 2.5°C. It was also found that Urban Greens have the minimum impact of Urban Heat Island effect while the concrete, asphalt, built up area had the maximum impact of UHI. For the planners the understanding of the mechanism of Land Surface Temperature's effect is very important for urban planning to enable greater control over surrounding environment. And in future the results from this study could be used for identifying warmer Municipal areas that could be transformed into sustainable environmental regions.

This study has some limitations. I could not get the meteorological ground data for the base years which could be used for the accuracy assessment.

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