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Impact Zonation and Mitigation of UHI (….through remote sensing & development of Blue-Green Infrastructure Network)

Atul Kumar[1], Indian Institute of Technology Roorkee (India)
Jagrati Sehgal[2], MIT School of Architecture Loni Pune (India)
Mahua Mukherjee[3], Indian Institute of Technology Roorkee (India)
Ajanta Goswami[4], Indian Institute of Technology Roorkee (India)

ABSTRACT

The world is moving towards urban transition–rural areas losing their identity and amalgamate into near urban sectors forming huge urban centers. The paper is concerned about the notorious effect of urbanization, where rapid and unplanned urbanization of cities and concomitant reduction in vegetation result in raised temperature compared to non-urban areas, creating a phenomenon known as the 'Urban Heat Island' (UHI).

The study focused on the surface UHI (SUHI), SUHI is the effect generated by heating of infrastructure and land surface. SUHI thermal trend can be identified in daytime as well as in nighttime. An image analysis procedure based on a two-dimensional Gaussian fitting to describe the surface urban heat island (SUHI) is developed using MODIS LST night-time data. This fitting provides a spatial extent, critical location, and magnitude of SUHI. SUHI parameters extracted for the Area of Interest (AOI) by exploring Temperature difference of the cells of the LST night band of MODIS. Landsat data used to extract LULC change pattern, the data processed in ArcGIS using maximum likelihood classification techniques. The study result shows that urban-rural temperature differences between the urban center and its surrounding areas show a maximum of 5℃ for the year 2016 at night whereas it was 4℃ for the year 2000 and 2008. This implies increase in heat island intensity. Ultimately, blue-green infrastructure is proposed for the critical zone of UHI.

Keywords: - SUHI (surface urban heat island), LST (Land surface temperature), Spatio-temporal, Blue-Green infrastructure

Introduction

An urban heat island (UHI) is defined as rise in temperature over an urban area with respect to surrounding area. A town or city has an ability to generate urban heat island (Oke, 1972). The boundary of the urban heat island is defined by a sharp change in magnitude of the skin temperature or land surface temperature (LST) over the area. The concept of urban heat island can be well understood by studying the urban area and the thermal characteristics with its surrounding area (Howard 1833, Shuzhen 1994). Surface modification due to urbanization leads to increases the imperviousness of the urban surface and thereby making the urban submission of climate warmer as compared to surrounding non-urbanized areas (Oke et.al. 1967). A recent survey reports reveal that 60% of the global population is concentrated in Asian countries among which India is the second most populated with 1.3 billion people (World Population Prospects, 2015). In recent times,

[1] Atul Kumar: [akumar5@ar.iitr.ac.in]

urban areas are growing population hubs with about 54% of the total world population living in urban areas. India is one of the fastest-growing countries in terms of population and economy, has an urban population of 410 million in 2014 (World Migration Report, 2015). This remarkable population can be stated responsible for the formation and expansion of UHI. According to the statistics of the World migration report, 2015, the urban growth in India is showing steady growth with an urban population of 410 million in 2014 and the estimated urban population by 2050 is 814 million. The tremendous growth in the number of cities with an average population of 1 million is from three in 1951 to fifty-three in 2014 respectively (World Migration Report, 2015).

Urban heat island can be studied by ground-based observation that involves collection of data from fix automatic weather station or by collecting the data along a transverse with thermometers mounted on a vehicle (Voogt and Oke, 2003). Several statistical methods have been developed to understand the change in growth of the city or urban area (Weng et al., 2004). The concept of remote sensing, to highlight the heat signature of an area, with respect to the surrounding was implemented from early 1970s (Rao et al., 1972). The size of the city plays an important role in determining the magnitude of the urban heat island (Oke, 1972). The study of urban heat island using thermal remote sensing becomes possible only because of advancement of sensor technology and the use of satellite, airborne and aircraft platforms. The surface temperature calculated using thermal data contains the effects of surface radiative and thermodynamic properties that include surface emissivity, moisture, and surface albedo, and contain the effect of the near-surface atmosphere.

Urban climates are influenced by a combination of process occurring at a variety of scales, which intern effects by the biophysical nature of cities and the structure of the urban atmosphere. The scale is considered as one of the important parameters while characterization urban heat island and modeling its different forms. Scale helps us to determine the size of the source area from where thermal influence originates and how it slowly changes the urban climate. A small-scale study of the UHI found inside the roughness layer (RSL) is known as microscale, where we study individual buildings, trees and the intervening spaces between the buildings. The mesoscale study involves plumes from individual local scale system, which extends vertically above and produce urban boundary layer (UBL) over the entire city. The growth of UHI has been monitor and study by numerous methods, of which we exploit MODIS thermal remote sensing data to measure the land surface temperature. The prime objective of the research is to assess the UHI pattern in the city of Gurugram and suggesting blue-green infrastructure measure to mitigate its effect.

Study area

Gurgaon or Guru-gram, the city is a glaring example of urban growth and emerges as a millennium city of the country. Witnessing modern reincarnation, the city has developed in both forms spatially and demographically. The state of Haryana was formulated in 1966 and Gurugram was one of its districts. Earlier most of the landmass was devoted to agriculture; the district has an agro-based economy. After 1990s Gurugram become hub for numerous job options this leads to the moving of a huge population to the city. Right now the city has become a financial and industrial center and contributing third highest per capita income. Gurgaon District is in the southernmost region of Haryana. Latitudinal and longitudinal expansion for the city is 27° 27’ 20” and 28° 32’25’’ latitude, and 76° 39’ 39’’ and 77° 20’ 50’’ longitude. The spatial expansion of the city is the part of National Capital Region, which is situated to the north of the district. The district has 1254 sq. km area. It has 1,514,432 population with a population density 1,241 people per square kilometer as per census 2011.

The AOI is selected in such a way that it covers urban pockets as well as an underdeveloped pocket to measure the temperature difference and to characterize UHI magnitude. Gurugram urban center is considered for the interested area for study. A shapefile is generated and with the layer of MODIS data for LST, a rectangle of dimension 30x30 is set for extraction of AOI. An extent of buffer zone is set under 30x30 tile, keeping center point at urban center of city. The rectangle for the area of interest has geographical dimension of 30 km x 30 km. It covers urban area as well as some part of Delhi and rural extent of Gurugram as buffer zone.

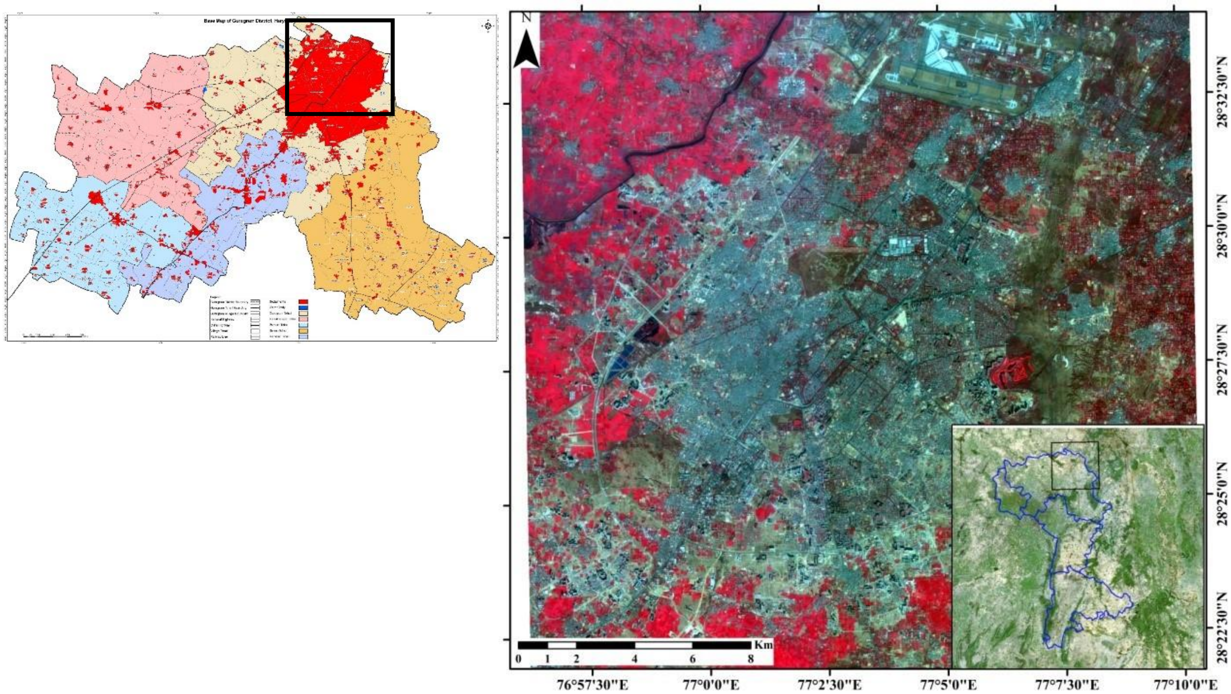


Figure 1. Area of interest for the study 30x30 km square marked on the Gurugram district map. *Source*: https://gurugram.gov.in/about-district/map-of-district/.

Methodology

The study methodology stars with the problem identification and literature study (case study) about the UHI effect. Objectives for the study is set under three separate work process, first is to analyze UHI change pattern, second is to analyze LULC change pattern and further relation is established with the LULC pattern and UHI intensity to get the result. Tools and techniques are set with the reference of literature review of the research paper that has worked on the UHI and LULC. For UHI change pattern MODIS data of spatial resolution 1km is used as the UHI effect can be identified at least over a city region, UHI characterization is done by estimating six parameters of UHI such as spatial extent, central location, orientation, and UHI intensity. LULC map is prepared for the area of interest considering 30km x 30km region of urban patch along with the buffer zone. Each extracted data has been plot on graph and relation has been set to get the result.

Mapping of the UHI zone

The land surface temperature depicts the radiative heat of the body or surface. In this research study, MOD11A2 product of MODIS data is used to extract LST day time and LST night time, over the AOI for the year 2000, 2008 and 2016. Gaussian fitting algorithm is applied to analysis the temporal assessment of LST for interested years. The study follows the same method to quantify the UHI intensity for the Gurugram city as described by Streutker 2002 in the research paper titled 'Satellite-measured growth of the urban heat island of Houston, Texas' (Streutker 2003). Streutker used least square fit method to developed Gaussian surface for the UHI magnitude over the area of interest and calculation of all variables such as (x,y) represents the location of a pixel, T (x,y) is the LST of a pixel at (x,y), T0 is the mean rural surface temperature, a_1 and a_2 are the coefficients determining spatial gradient of rural temperature and UHI (x,y) is the pixel-based heat island intensity. The method used to determine the UHI magnitude is designated as a0 along with spatial extent (a_x and a_y), orientation (ϕ) and the central location (x_0 and y_0) of the heat island. The version v005 of MOD11A2 of 8 day product from band 31 (10780 – 11.280 µm) and band 32 (11.770 – 12.270 µm) of terra satellite is used for the UHI change pattern study, out of 12 layers the layer number 4 is used for processing to extract LST as this layer provide LST night data. Accuracy of MODIS LST product is better than 1K in most of the cases. 39 out of the 47 scenes give an accuracy of land surface temperature better than 1K (D. Zhou et al. 2014). The data set acquired from the MODIS has sinusoidal projection system and it needs to be changed into Lambert Conformal Conic (LCC) projection of datum WGS_1984. MODIS provides raw dataset in HDF (hierarchical data format), the raw data set in HDF format is processed to extract SDSs scientific datasets and store as raster imagine file with the spatial reference system information. The SDSs acquired from the extraction of raw dataset provide LST 1_km in raster imagine file which is further processed for mosaicking and LST map is extracted for the AOI (Gurugram city), using input shapefile of Gurugram city and its neighboring area.

In order to perform the fit, each rural temperature image is fit to a planar surface and the rural temperature image is subtracted from LST image which enhanced the urban temperature signature. Mathematically this step is expressed as $T(x,y) = T_0 + a_1x + a_2y$; where T_0 is the mean temperature in degrees centigrade, a_1 and a_2 are the longitudinal and latitudinal measure in ºC / km. The enhanced urban temperature signature provides the SUHI signature. The process of linear fitting is executed in Matlab, 2012a.

Finally, a 2D Gaussian surface is developed in Matlab along with 12 parameters. Major advantage of this method is that it provides the difference in temperature between the urban and the surrounding rural area. The expression used to determine SUHI intensity on least square technique is as:

$$SUHI(x,y) = a_0 \times \exp\left[-\frac{\{(x-x_0)\cos\phi+(y-y_0)\sin\phi\}^2}{0.5a_x^2} - \frac{\{(y-y_0)\cos\phi+(x-x_0)\sin\phi\}^2}{0.5a_y^2}\right] \quad (1)$$

Equation 1 Equation for SUHI intensity Source: A Stable Gaussian Fitting Procedure for the Parameterization of Remote Sensed Thermal Images

In this expression (x, y) represents the location of a pixel, a_0 is the magnitude of the UHI, spatial extent (a_x and a_y), orientation (ϕ), and the central location (x_0 and y_0) of the heat island. Spatial extent provides the extent of SUHI horizontally. The AOI has been plot in the form of ellipse with a_x and a_y as major and minor axis and the angle ϕ is the angle made by major axis with x-axis and the central location (x_0 and y_0) gives the critical location with respect to SUHI intensity, it also provides the shifting of critical UHI point with respect to map central location. The central location

(x_0 and y_0) is the center of the ellipse and tells the point of highest SUHI intensity, further spatial extent is represented with concentric ellipse in which the inner ellipse represents the spatial extent up to which SUHI magnitude has 61% of its maximum values it marked as A_61% the outer ellipse defines the region having SUHI magnitude greater than the 1.0 k and marked as A_1K.

Initial UHI parameter estimation: a least-square fit is performed. Equation 1 can be exactly transformed into a linear equation with the use of the logarithm and can be expressed as a linear equation with six unknown variables:

$$\ln\big(SUHI(x,y)\big) = a_1x^2 + a_2xy + a_3y^2 + a_4x + a_5y + a_6 \qquad (2)$$

Equation 2 logarithmic SUHI intensity (source: A Stable Gaussian Fitting Procedure for the Parameterization of Remote Sensed Thermal Images)

For equation 2 the variables a_i is directly calculated by using linear regression. Gaussian fitting: starting from the initial guess parameters, a nonlinear data-fitting in a least-squares sense is executed. It is an iterative fitting procedure implemented with the function lsqcurvefit.m (Matlab Optimization Toolbox) that finds the coefficients that best fit the Gaussian function to the data (Anniballe and Bonafoni 2015). All the parameters directly computed with equation 1 and equation 2 as well as the spatial extent. The correlation coefficient and R square between the Gaussian model and the SUHI is also evaluated. The graphical representation also developed for the SUHI, it provides better understanding of the shape and orientation of urban heat island. 2D Gaussian surface and 1D plot of Gaussian surface along major and minor axis.

Mapping Land Use Land Cover (LULC)

The LULC for the Gurugram city considering some spatial extent as a buffer zone is prepared using LANDSAT data. For the year 2000 the data of LANDSAT -5 is used whereas for the year 2008 and 2016 LANDSAT-7 and 8 are used respectively. LULC map is prepared using supervised classification in ArcGIS, the layers like build-up, water, vegetation (dense and sparse), barren land, etc. are classified.

Blue-Green Infrastructure

Green Infrastructure provides ecosystem services and maintains thermal balance by regulating the fresh air supply, reduced surface runoff and thus modify the local microclimate through the production of oxygen. They help in capturing carbon and reducing the level of smog, which are the reasons for rising temperature.

The use of vegetation is the most effective measure to reduce the UHI effect (Wilmers F 1988). Grass over open land helps in providing low resistance to airflow, which might enhance cooling by convection (Bowler, 2010). Based on studies conducted, it has been found out that urban parks could reduce the air temperature of the surrounding area by 4°C (Oke 1998; Jonsson 2004; Zoulia Santamouris and Dimoudi 2009). Dense tree shade on the street with minimal traffic has the cooling effect of 2.2°C (Tsiros 2010). 21% to 26% of the surface area in cities is comprised of roof surface (Wong 2005) therefore, few green roofs over some buildings would not be enough to provide large effect on a local scale in spite in some special cases. Green roofs absorb heat and filter the air and keep the air temperature low (Getter 2006).

In spite of green vegetation other high albedo materials also help in controlling temperature. By the use of permeable pavement air temperature can be reduced up to some extent. Thus, repaving streets with cool paving materials is expected to lower urban air temperatures (Taha 1997). An increased amount of water bodies may reduce temperature due to their evaporative action and enhanced wind speed (Robitu et al. 2006).

Vegetation lower surface and air temperature through evapotranspiration. Through the process of evaporation, energy gets transferred from the atmosphere and hence, links the energy balance of the hydrological cycle and if there is less amount of vegetation in the environment the remaining energy would be responsible for the formation of extra heat which is responsible for the formation of UHI. Therefore, the provision to design network of these green interventions is the most effective and efficient measure to control the intensity of UHI.

Result and discussion

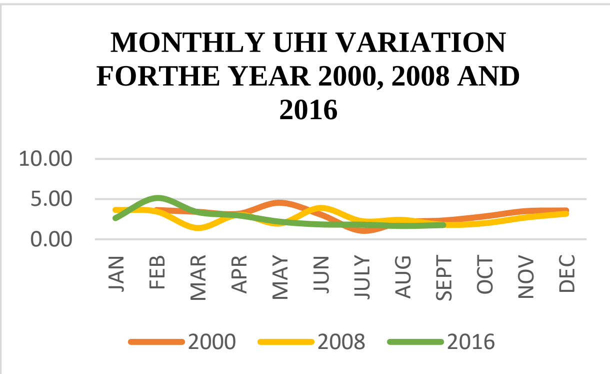
The SUHI island is characterized for the year 2000, 2008 and 2016 for the densest urban patch of 30km x 30km area in Gurugram with remotely sensed data of MODIS images and plotted, it provides not only monthly UHI magnitude variation (a0) but also the spatial extent (a_x and a_y) along with the orientation (ϕ) central point (x_c, y_c). Data is retrieved using Matlab 2012 and after analyzing the result and collected in a tabular form as shown in table below. It is noticed that the month of MAY and JUNE fall under the highest UHI intensity for the year 2000 and 2008 respectively were as for the year 2016 it's shifted to month of FEBRUARY. For temporal variations of the UHI magnitude graph of months vs. average UHI magnitude has been plot. For spatial extent of UHI effects over the city LST map has been prepared as well as variation of monthly spatial extent graph is plotted. LULC map is prepared considering four classes (build-up, vegetation, water, and barren land) with specific color code.

The urban-rural temperature differences between the urban center and its surrounding areas show a maximum of 5℃ for the year 2016 at night whereas it was 4℃ for the year 2000 and 2008 this implies increase in heat island intensity. The aerial extent A-61 defines the area's spatial extent up to which SUHI intensity lower down to 61% were as A-1K defines the area SUHI intensity is considerable or greater than threshold value that is 1.0 k. monthly variation graph for the spatial extent depicts that for the year 2016 maximum value of the A-61 is 87 km^2, for the year 2008 and 2000 the maximum aerial extent is 73 km^2 and 74 km^2. The area of A-61 for inner ellipse and area A-1k for outer ellipse is increasing continuously during last years as shown in the plotted excel sheet. LST map developed for the area also show the increasing spatial extent of heat island effect along with the change of geographical landscape or urban sprawl, map with blue colour code show the extent of UHI effects for the year 2000 and 2008 it was concentrated near national capital region of Delhi over the time period of urban sprawl its extent increase.

Table 1 Average monthly UHI magnitude and spatial extent for the year 2000, 2008 and 2016

Months	2000		2008		2016	
	UHI	SPATIAL	UHI	SPATIAL	UHI	SPATIAL
Jan			3.65	33	2.63	42
Feb	3.64	31	3.46	40	5.13	54
March	3.41	35	1.40	42	3.38	46
April	3.17	34	3.04	41	2.97	50
May	4.54	45	1.96	34	2.19	45

June	3.09	27	3.89	27	1.85	44
July	1.06	74	2.26	33	1.82	44
Aug	2.12	47	2.41	25	1.65	52
Sept	2.33	37	1.80	48	1.76	56
Oct	2.84	29	1.99	26		
Nov	3.50	30	2.70	34		
Dec	3.58	27	3.18	36		



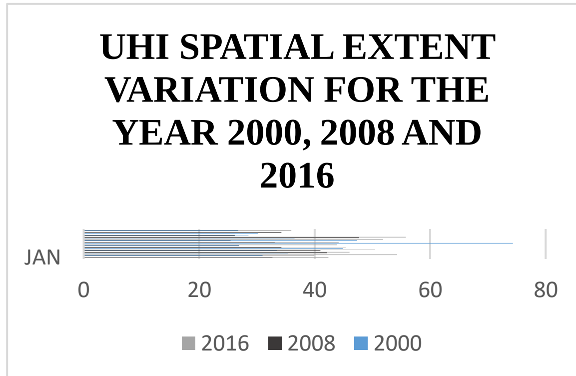


Figure 2 (a) graph between UHI magnitudes vs months (b) graph between spatial extent vs months

LULC map of the area depicts drastic changes in urban patches from the year 2000 to 2016. In the year 2000 and 2008 the area allocated for the urban or build-up was 95 square km and 242 square km respectively whereas for the year 2016 it increases to 287 square km. During the 16 years of period Gurugram experienced about 200% hike in urban regions. Waterbody shows constant trend. Vegetative land patches are kept on depleting from 188-kilometer square to 52-kilometer square in 2016.

Table 2 LULC classification and area for the year 2016 / 2008 / 2000

LULC			
Class	**2016**	**2008**	**2000**
Build Up	287.6526	242.7192	95.3343
Vegetation	52.4349	66.5217	187.7085
Barren land	247.5504	279.2241	305.1171
Water body	1.6434	0.8145	1.1214
Total	**589.28**	**589.28**	**589.28**

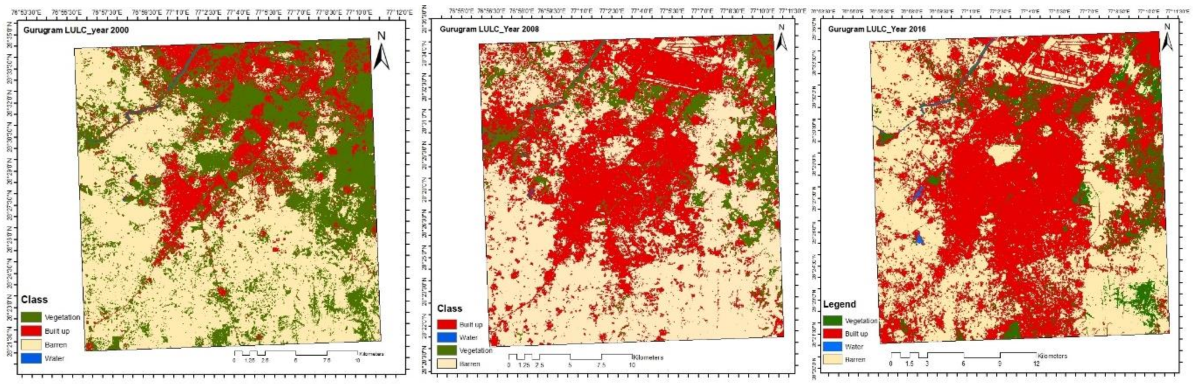
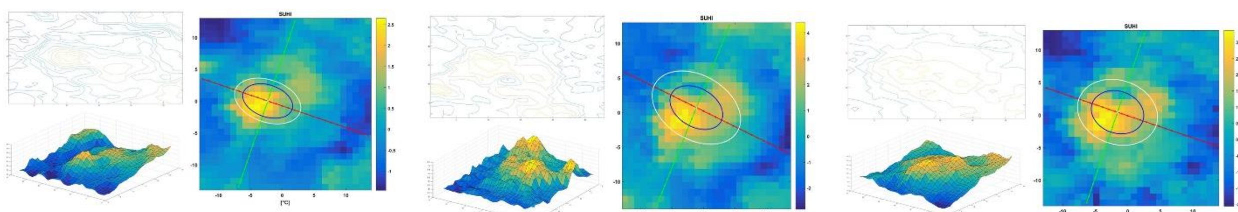


Figure 3 LULC for year (a) 2000/ (b) 2008/ (c) 2016

Conclusion

The study quantifies the present status of urban heat island in the Gurugram city area, it also identifies the heat island spatial pattern and its temporal variation for the area of interest. The result implies that due to urban growth the city is feeling more heat as change in its local climatic condition and the city is experiencing less cold in winter season as well as intense hot in summer season. Although heat island effect is also present in day time with intense magnitude the study focus on night time as to get good signature of SUHI. For analyzing the UHI Gaussian surface method used which was developed by Streutker in 2002, this method has been used for various cities throughout the globe. For Indian city this method is new; the main purpose of this study is to understand the heat island effect in terms of magnitude and spatial extent along with the land use land cover change of the city.



(A) (B) (C)

Figure 4 Gaussian surface developed for AOI (A) 2000, (B) 2008, (C) 2016

In this study urban heat island is quantify for the three years considering an interval of 8 years that is 2000, 2008 and 2016 as well as land use land cover map is also developed to set the relation between heat island critical point and urban setting. The UHI signature is studied for the night LST which shows the radiant temperature of the materials. UHI magnitude for all the months for the year 2000, 2008 and 2016 is estimated and graph of monthly variation of average UHI magnitude is plotted for the three marked years. It is found that for the year 2000 and 2008 UHI intensity was maximum for the month of May and June respectively whereas for the year 2016 it is shifted to the month of January. Land use land cover map also shows increasing trend as the urban patch increase from 95 km^2 in the year 2000 to 287 km^2 in the year 2016. With the increase of urban area the spatial extent of UHI is also increased. The critical point of UHI is found at the urban center of the city with variable spatial extent. Here, regional study is carried out to quantify

UHI intensity as MODIS provides data of 1 km spatial resolution as the phenomenon of UHI can be identified at city or municipality region level. LULC map is prepared with the processing of Landsat data as it provides 30m spatial resolution. The plot and all other intermediate result show the present status of UHI effect in Gurugram city.

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