TRENDS OF SURFACE URBAN HEAT ISLAND IN PAST FEW YEARS IN THE CITY OF AHMEDABAD

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ABSTRACT:
An urban heat island (UHI) effect is observed in metropolitan areas which are significantly warmer than its surroundings suburban or rural areas. Its major impact is observed during night time after three to five hours of sunset in urban areas. Hence, earlier prediction of UHI effect is required in order to mitigate its hazardous effect. At present, the existing prediction methods are based on numerical estimations. In this paper, we have used satellite data, concerning the surroundings of Ahmedabad City in Gujarat, India. Land Surface Temperature, Normalized Difference Vegetation Index (NDVI) and Top of Atmospheric (TOA) are calculated using this data and with the help of suitable digital image processing software.

Keywords: *UHI effect, LST, NDVI, TOA*

1. INTRODUCTION

An urban heat island (UHI) effect is observed in metropolitan areas which are significantly warmer than suburban or rural areas. Its major impact is observed during night time after three to five hours of sunset in urban areas. The UHI effect has been extensively studied for several cities of India in order to mitigate its harmful effect. India, being a growing economy, has undergone rapid urbanization in the last few decades. The phenomenon of UHI which is associated with urbanization has not drawn much attention from the scientific fraternity within the Indian subcontinent. Only a few studies have come up over a large span of time [1].

Hence, earlier prediction of UHI effect is required in order to mitigate its hazardous effect. At present, the existing prediction methods are based on numerical estimations. It is required to predict UHI effect area-wise. So that it possesses a synergistic effect in the speed of reducing UHI effect [2].

Satellite data is extensively used for study and analysis of UHI effect and LST derived from satellite imageries is used for the same. UHI effect, when studied using LST, is referred to as the surface urban heat island (SUHI) effect [3]. LST is one of the key parameters controlling the physical, chemical and biological processes of the Earth and is an important factor for study of urban climate [4]. LST has been utilized in numerous heat-balance, climate modeling and global-change monitoring studies [1, 3, 4].

Land cover information can be acquired effectively by visual image interpretation of satellite imagery or after applying enhancement routines and also by imagery classification. While elevation of any part of a city usually gives land use land cover patterns, the natural landscape consisting of bare ground or vegetation cover is converted into any one of the urban surfaces or even into change in vegetation cover. The objective of the present study is to develop a linear model to predict the LST of any area on the basis of historical temperatures and parameters representing vegetation, RD and elevation of that area.

In this paper, we have used Landsat-8 multispectral data, concerning the surroundings of Ahmedabad City in Gujarat, India. Land cover information is extracted, using suitable digital image processing tools.

Landsat-8 is required to return 400 scenes per day to the USGS data archive. Landsat 8 has been regularly acquiring 550 scenes per day. This increases the probability of capturing cloud-free scenes for the global landmass. The Landsat 8 scene size is 185-km-cross-track-by-180-km-along-track. The nominal spacecraft altitude is 705 km. Cartographic accuracy of 12 m or better (including compensation for terrain effects) is required of Landsat 8 data products. In Table-1, Landsat-8 bands are summarized with its application.

Table 1: Landsat-8 Bands

Landsat-8 Operational Imager (OLI) and Thermal Infrared Sensor (TIRS) (Launched February 11, 2013)	Bands	Wavelength (micrometers)	Resolution (meters)	Applications
	Band 1 - Coastal Aerosol	0.43 - 0.45	30	whale population, bathymetry, aerosols(cloud detection)
	Band 2 – Blue	0.45 - 0.51	30	deep water imaging, smoke plumes, atmospheric haze and clouds, clouds, snow and rock
	Band 3 – Green	0.53 - 0.59	30	plant vigor and vegetation, algal and cyanobacterial blooms, urban recreation
	Band 4 – Red	0.64 - 0.67	30	soil types and geologic features, built and natural environment, chlorophyll absorption
	Band 5 - Near Infrared (NIR)	0.85 - 0.88	30	biomass content, archaeological sites, normalized difference vegetation index (ndvi)
	Band 6 - SWIR 1	1.57 - 1.65	30	moisture content, cloud/smoke penetration, mineral exploration
	Band 7 - SWIR 2	2.11 - 2.29	30	water properties, irrigation practices, mineral mapping
	Band 8 – Panchromatic	0.50 - 0.68	15	Pansharpening
	Band 9 – Cirrus	1.36 - 1.38	30	cirrus clouds
	Band 10 - Thermal Infrared (TIRS) 1	10.60 - 11.19	100	volcano activity, urban heat, weather prediction
	Band 11 - Thermal Infrared (TIRS) 2	11.50 - 12.51	100	

source: - Landsat 8 band designations. (2019). Usgs.gov. Retrieved 3 April 2019, from https://www.usgs.gov/media/images/landsat-8-band-designations

2. RELATED WORK

Due to hazardous results of the UHI effect, it is necessary to predict it with long-term and short-term implications. There are various models, methods and tools used to predict UHI intensity in urban areas are given below and discussed in detail.

2.1 Methods used to predict UHI intensity

In this section, the prediction methods for UHI are discussed on the basis of their application and input parameters. Once the UHI intensity in a specific area is predicted, the corresponding mitigation strategy can be identified and applied in advance in order to prevent or reduce the UHI intensity.

2.1.1 Local Climate Zone classification

Kotharkar & Bagade used Local Climate Zone (LCZ) method to evaluate urban climatic zones in the Nagpur city [5]. In this, remote sensing data is used to calculate NDVI, LST and LULC. They have taken meteorological data from the regional meteorological department of Nagpur city. They have used HOBO data logger for stationary data. This paper uses temperature buffer analysis, sensor lag determination, forecasting, outlier analysis and Pearson-correlation technique. They estimated CLHI (Canopy Layer Heat Island) through a traverse survey in the range between 1.76 – 4.09 °C within the built class. However, they admitted the need of more parameters to predict UHI more precisely.

2.1.2 Observational method using Automobile Devices

In this method, data is collected using different sensors mounted on devices. Mutani et al. had analyzed the UHI effect in the city of Turin [6]. He used multiple regression models and established correlation between air temperature and urban parameters like urban morphology, solar radiance, albedo coefficient etc. These devices are placed on various urban structures or urban areas having high elevation or urban morphology. The result shows 1-1.5 °C with the average air temperatures respectively in summer-time and winter-time. However, for future research they want to improve prediction models by using hourly weather data.

Amirtham analyzed the impact of urbanization on UHI intensity in the city of Chennai [7]. He used HOBO data logger for collecting temperature data to analyze UHI intensity and took reference data from Numgambakkam Meteorological station as a data source. In his studies, he revealed the presence of a cool valley effect in the city of Chennai at the time of winter with a temperature difference of 10.4oC in summer and 3.7 °C in winter.

2.1.3 Linear Time Series (LTS) Model with least-square method

Mathew et al. used this model to predict UHI intensity in Ahmedabad [8]. They developed a linear model for prediction of LST in any area based on historical temperatures and parameters representing vegetation, road density and elevation of that area. They used the last 10 years of MODIS and ASTER. LST can be predicted from previous year LST images with good accuracy and will be helpful to monitor SUHI effect which is helpful in planned development city. They discovered high correlation between the prediction model and observed LST with an average regression coefficient (R2) value of 0.96 (of LST). However, LST models are sensitive to outliers and they have a tendency to over-fit data.

2.1.4 GIS Method

Nakata-Osaki et al. developed THIS tool based on GIS technique [9]. They calculated UHI maximum intensity along with height-width ratio. They concluded that the UHI maximum intensity increases when the height-width ratio goes up, but the urban canyons with greater roughness result in UHI maximum intensity values of around two times smaller than canyons with less roughness for the same value as the height-width ratio. They analyzed the geographical measurements in the city of f São José do Rio Preto with the altitude above sea level, census and distance in kilometer from town to center. In their work, all the linear regression models had a relative error lower than 10 %. The results show 1-1.5 °C UHI intensity with the average air temperatures respectively in summer-time and winter-time; and of 2.6-2.46 °C with the minimum air temperatures respectively in summer-time and winter-time. However, THIS tool considered temperature data as the main affecting factor.

2.1.5 Ant Colony

Diamond et al. analyzed the UHI effect of three cities using an ant colony algorithm [10]. They used data from Dryad Digital Repository. They collected acorn ants from urban and rural populations across three cities in the eastern USA viz. Cleveland, Ohio, Cincinnati, Ohio, Knoxville and Tennessee. They predicted an increase in heat tolerance of the urban population across each urbanization gradient. The results of this study suggested that the phenotypic changes in thermal tolerance that they observed in acorn ants from urban populations are adaptive. They linked phenotypic shifts in temperature tolerance with environmental changes in temperature. Among three selected cities, two cities produce the same result as their urban morphology is quite similar. However, Temnothorax is a very heat-tolerant species as compared with other ants; it is possible that low-latitude populations are beginning to push the evolutionary limits of heat tolerance, leading to reduced evolved response with increased warming in cities.

2.1.6 Artificial Neural Network (ANN)

Ashtiani et al. utilized the Artificial Neural Network (ANN) algorithm to predict the indoor air temperature and relative humidity in a house where indoor and outdoor temperature and relative humidity were measured every 15 min for 30 days [11]. They performed cross-comparison of a traditional and an advanced heat warning model with the help of the regression and ANN models respectively. The developed regression and ANN models were used to predict the hourly indoor dry-bulb temperatures of units located in downtown Montreal and the heat wave in July 2010. It is well established that outdoor dry-bulb temperature has significant influence on the indoor environment thermal condition. The variation of predicted results of ANN model about maximum and minimum indoor dry-bulb temperatures are 2.64ºC and 1.99ºC, respectively. However, they assumed many variables in their study; for example, total building volume is assumed to be proportional with building thermal mass. Apart from this, the value of emittance, ε, is assumed to be one.

Moustris developed the ANN model for complex human thermal comfort index associated with urban heat and cool island patterns [12]. This model has Penteli and Ilioupolis as study areas. The values of Physiologically Equivalent Temperature (PET) index for a number of different locations with different urban environment configurations were predicted applying the developed ANN models for the warm period of the year 2007. The multi-layer perceptron ANN models were developed using the back-propagation training algorithm to predict PET hourly values.

2.1.7 Maximum Likelihood, Physical Scaling (using downscaling model) and other methods

Geoffrey and John analyzed UHI intensity in Manchester city by developing their own method [13]. The parameters used in this work were wind speed, the cloud cover, and the solar radiation. It is used to predict the hourly values of UHI intensity all over the year. They collected weather data from the British Atmospheric Data Centre. However, they had not included temperature as a factor in their work.

Gaur analyzed the Surface Urban Heat Island (SUHI) of 20 Canadian cities [14]. They collected MODIS data for their work. They analyzed data from 2002 to 2012. Results of UHI effect are encouraging in these regions, that is, 16 out of 20 cities were facing positive impact while the other 4 cities were experiencing negative impact of SUHI phenomena. They selected a Physical Scaling downscaling model for this work. Various parameters viz. size, elevation, and surrounding land cover of the city are considered in the study to predict UHI intensity. In addition, they estimated future predictions for the same study area. However, as the nature of UHI varies and it is based on anthropogenic activities of humans, it is possible that the estimation may differ.

Khandar and Garg used maximum likelihood method to analyze the Nagpur area and its surrounding [15]. They utilized Landsat ETM+ data of Nagpur and its surrounding area. They selected a mono window algorithm to retrieve Land Surface Temperature (LST). They also analyzed the correlation between NDVI and LST and observed that LST is weakening where NDVI is high. The result shows that UHI intensity is high in the center of Nagpur city.

3. STUDY AREA

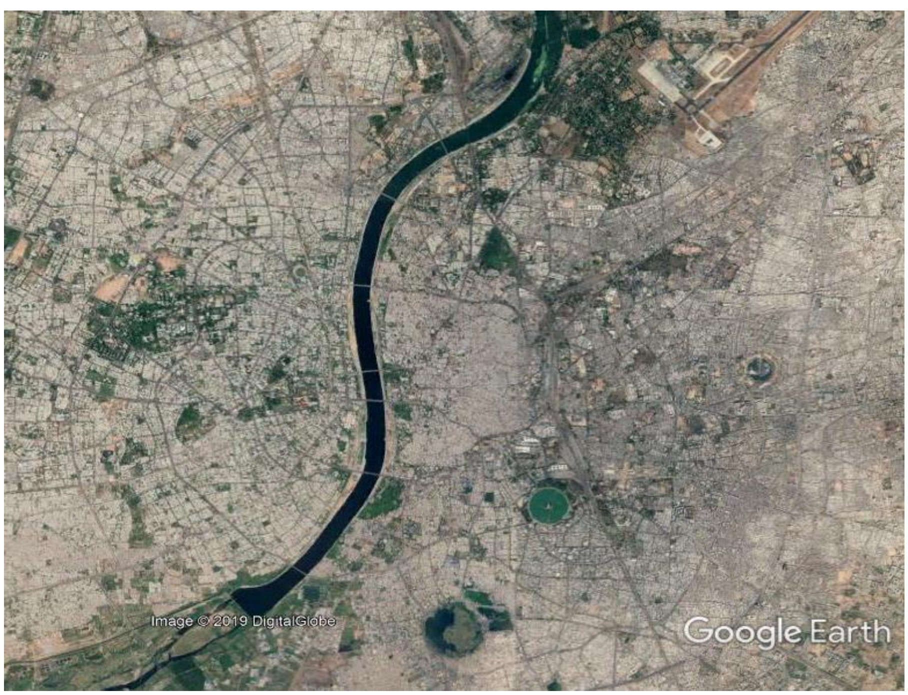

Figure 1: Google Earth Image of Ahmedabad City

Ahmedabad, located on the bank of river Sabarmati between 22^o 56' and 23^o 06' North Latitudeand 72^o 37' and 72^o 41' East Longitude, is the largest city in the Gujarat state of India. It is the seventh largest metropolitan area of India, with a total population of 7,208,200 (Census of India 2011), while the population in 2001 was 5,893,164. The Ahmedabad study area and its geographic location is shown in fig. 1. Climatic condition of Ahmedabad is semi-arid and hot. Climate here is extremely dry during the summer season from March to mid-June. The average annual rainfall over the area is 782 mm, although it varies considerably every year. It occurs generally during the months of June to September. The average relative humidity is 60% with a maximum of 80% to 90% during the rainy season. Ahmedabad accommodates about 11% of the state population but accounts for about 21% of the vehicles registered in the State. The number of motor vehicles registered in Ahmedabad was 1.49 million (73% were two wheelers) in the year 2004. The vehicular population of the city has increased to 3.15 million now. This rapid growth of vehicles has worsened the transport situation to a significant extent and has resulted in an increase in air pollution. Within the boundaries of Ahmedabad Municipal Corporation (AMC), the land use for residential and commercial categories, which was 35%and 2.5%, respectively in 1997 has been proposed to be increased to 44% and 3.4%, respectively in the Master Plan of 2011 [32].

As the UHI phenomenon indicates a warmer thermal climate of urban land, compared to non-urbanized areas, the study area must include sufficient non-urbanized/sub-urban areas outside the urban area for UHI studies. The urban area boundary of Ahmedabad city has been derived by extracting urban area polygon from the QGIS. The study area covers approximately 305 km^2. The LST image of the study area has (30, -30) pixel size. Figure 1 shows the Google Earth© image of the study area and urban area of Ahmedabad city.

4. METHODOLOGY

To extract Land Surface Temperature from Landsat image certain procedures are to be followed. The procedure to calculate LST from Landsat-8 image is discussed here. The multispectral data is preprocessed and various calculations are carried out to check the presence of UHI effect. As shown in table 5.1, multispectral data of these datasets are taken from the USGS website.

In step-1 Top of Atmospheric (TOA) spectral radiance is calculated. The TOA signifies spectral irradiance and the solar zenith angle useful in measurement of incident solar radiance.

In step-2 TOA is converted into At-Satellite Brightness Temperature. The equation is applied in step-2.

In step-3 Normalized Difference Vegetation Index (NDVI) is computed. It will show the ratio of land and vegetation with concentrated density of land.

In step-4, the proportion of vegetation Pv is calculated using obtained NDVI. This Pv is partially proportional to NDVI and UHI effect.

In step-5, The Emissivity ε is calculated using Pv and constant. In step-6, the Land Surface Temperature is calculated using previously obtained parameters.

In table 1, Calculated UHI parameters are given with periods. As it is analyzed from the given table, the UHI effect is present in the city of Ahmedabad. It can be reduced by using and implementing various vegetation strategies.

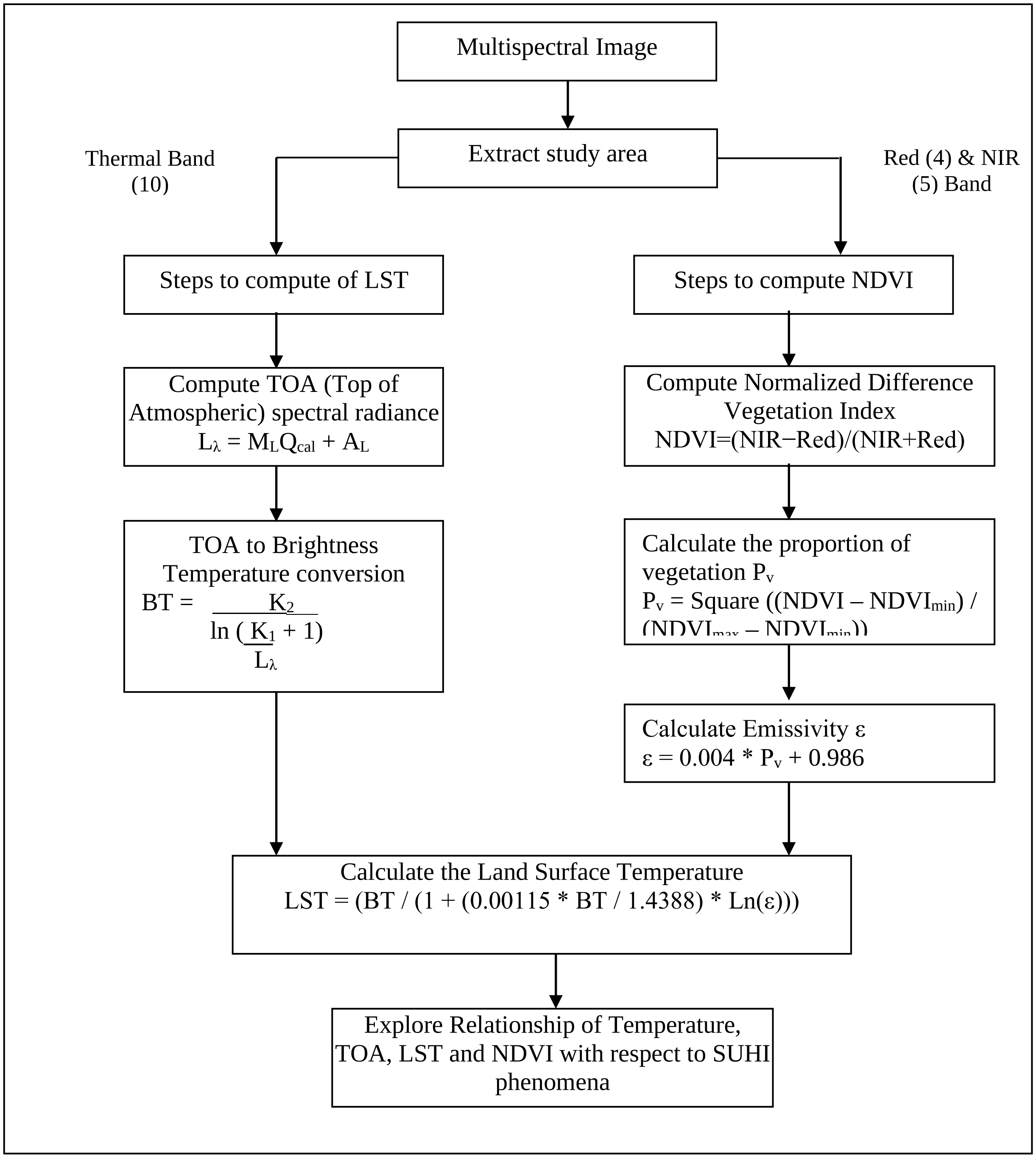

Figure 2: Applied Methodology for LST Calculation

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Table 1: Selected Data for Implementation from Landsat-8

No.	Image Entity ID#	Image Acquisition Date
1.	LC08_L1TP_149044_20130518_20170504_01_T1	18th May 2013
2.	LC08_L1TP_148044_20140530_20170422_01_T1	30th May 2014
3.	LC08_L1TP_149044_20150524_20170408_01_T1	24th May 2015
4.	LC08_L1TP_148044_20160519_20170324_01_T1	19th May 2016
5.	LC08_L1TP_148044_20170522_20170526_01_T1	22nd May 2017
6.	LC08_L1TP_149044_20180516_20180604_01_T1	16thMay 2018

1) Compute Top of Atmospheric (TOA) spectral radiance

$$L_\lambda = M_L Q_{cal} + A_L \quad \ldots (1)$$

Where,
L_λ = TOA spectral radiance (Watts/(m2 * srad * μm)),
M_L = Band-specific multiplicative rescaling factor from the image header (Radiance Multiplicative Band_x, where x is the band number to be corrected),
A_L = Band-specific additive rescaling factor from the image header (Radiance Additive_Band_x, where x is the band number to be corrected),
Q_{cal} = Digital Number of the band to be corrected

2) Conversion to At-Satellite Brightness Temperature

TIRS band data can be converted from spectral radiance to brightness temperature using the thermal constants provided in the metadata file:

$$BT = \frac{K2}{\ln\left(\frac{K1}{L_\lambda} + 1\right)} \quad \text{.... (2)}$$

Where,
BT = At-satellite brightness temperature (K)
L_λ = TOA spectral radiance (Watts/(m2 * srad * μm))
K1 = Band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_x, where x is the band number, 10 or 11)
K2 = Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x, where x is the band number, 10 or 11)

3) Compute Normalized Difference Vegetation Index (NDVI)

NDVI = (NIR−Red) / (NIR+Red) .... (3)
Where,
NIR = Near Infrared Band-5 of Landsat-8 image data
Red = Band-4 in Landsat-8 image data

The computation of the NDVI is important because, subsequently, the proportion of vegetation (Pv), which is highly related to the NDVI, and emissivity (ε), which is related to the Pv, must be calculated.

4) Calculate the proportion of vegetation P_v

P_v = square ((NDVI – NDVImin) / (NDVImax – NDVImin)) .... (4)

Usually the minimum and maximum values of the NDVI image can be displayed directly in the image.

5) Calculate Emissivity ε

$\varepsilon = 0.004 * P_v + 0.986$ .... (5)
Simply apply the formula in the raster calculator, the value of 0.986 corresponds to a correction value of the equation.

6) Calculate the Land Surface Temperature

LST = (BT / (1 + (0.00115 * BT / 1.4388) * Ln(ε))) .... (6)
This is the final equation of the process of deriving Land Surface Temperature (LST). The final product is shown below in the image.

5. RESULTS AND DISCUSSION

By doing the analysis, we observed that in the city of Ahmedabad loud cover is reducing in the month of May. As compared with 2018 data, 2013 possesses more cloud cover (Landsat-8 band 1). Also, the city area in Ahmedabad which is included in the east zone and south zone are SUHI prone areas. New west zone is less prone to SUHI effect.

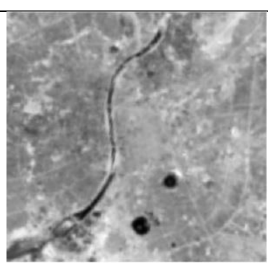
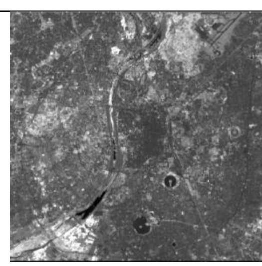
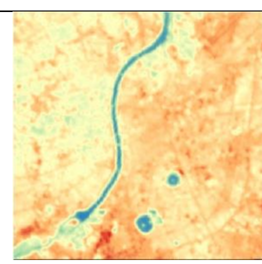
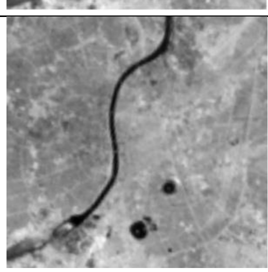
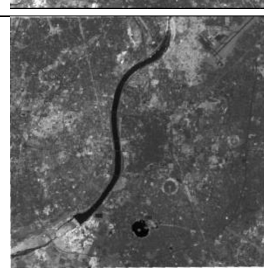
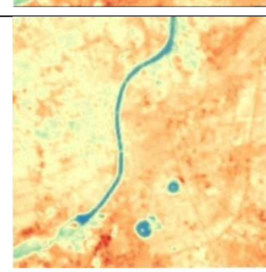
As per observation in table 2, UHI effect is expected maximum at the midnight period in the month May and June. Climate change also affects UHI, so clouds are observed in some multispectral images.

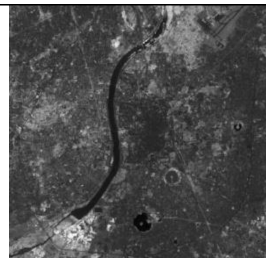
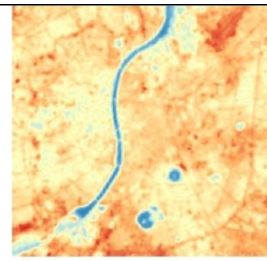
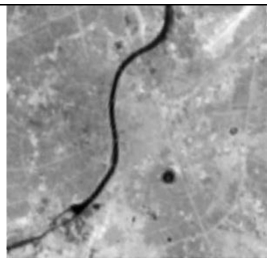
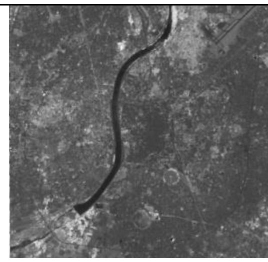
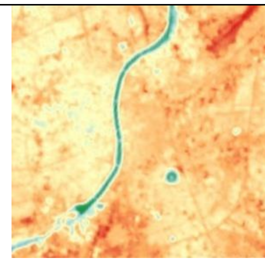
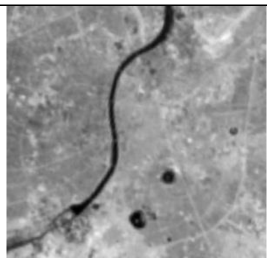
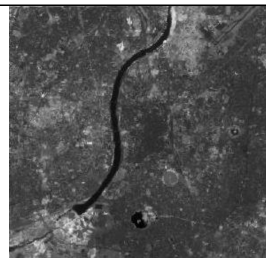
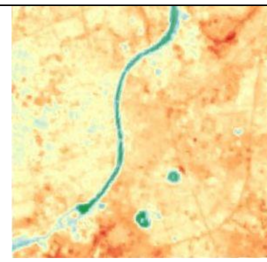
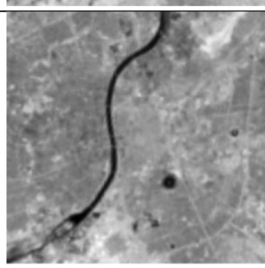
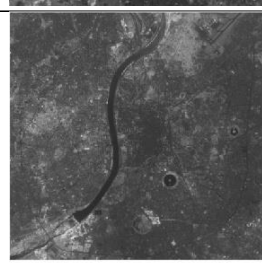
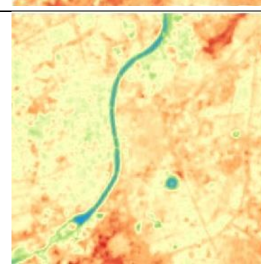
In table 3, data results are given with remote sensing images. The software tools are used to calculate LST of Ahmedabad. The results are highly hopeful. It means that Ahmedabad is able to mitigate UHI effect.

Table 2: Calculated UHI parameters

Parameter		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
NDVI	Min	-0.0683	-0.0784	-0.0335	-0.0927	-0.0322	-0.027
	Max	0.401	0.53	0.513	0.48	0.468	0.361
Top of Atmospheric (TOA) (Kelvin)	Min	304.845	302.331	301.896	304.484	301.197	302.662
	Max	322.341	318.6	314.638	323.06	315.274	318.452
LST (Kelvin)	Min	106.52	106.51	106.45	106.771	106.36	106.54
	Max	108.47	108.47	108	108.968	108.063	108.43
Brightness Temperature conversion (degree Celsius)	Min	31.695°C	29.181°C	28.746°C	31.334°C	28.047°C	29.512°C
	Max	49.191°C	45.45°C	41.488°C	49.91°C	42.124°C	45.302°C

Table 3: Calculated UHI parameters with period and images

Period	TOA (10)	NDVI (4-5)	LST	Min-Max Temperature (6 pm - 12pm)	Average Temperature (May)
2013-05-18				44-32°C	35 °C
2014-05-30				43-33°C	35 °C

2015-05-24				39-34°C	36 °C
2016-05-19				49-35°C	36 °C
2017-05-22				40-32°C	35 °C
2018-05-16				45-35°C	37 °C

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