TEMPORAL ANALYSIS OF SUMMER-TIME URBAN HEAT ISLAND INTENSITY OVER FIVE METROPOLITAN CITIES IN INDIA

Nithiyanandam Yogeswaran[1*], Sayona S Jacob[2], Vimalathitthan Shanmugam[1]

[1]TERI University, New Delhi – 110 070, India. Email: nithirsgis@gmail.com
[2]Indian Institute of Information Technology and Management, Thiruvananthapuram – 695 581, India.

KEYWORDS: Urban Heat Island, Land Surface Temperature, Temporal Analysis, Urbanisation and Delhi.

ABSTRACT: The world is undergoing an unprecedented rate of urbanization. About 70% of global energy is consumed in urban areas, which accounts for around 2% of the world's land surface. Energy consumption in urban areas correlates positively with changes in urban micro-climate which contribute to elevated air temperature compared to rural areas with the temperature differences being between 1 and 3 °C. This phenomenon is called Urban Heat Island (UHI), which is traditionally studied by measuring air temperature using thermometers. With the advent of remote sensing technology, Land Surface Temperature (LST) (which explains most of the variation in air temperature) is used to map the impact of UHI over a large area. The present study examined the intensity of UHI over five selected Indian metropolitan cities (Ahmedabad, Chennai, Delhi, Kolkata and Mumbai) for the period 1981-2016. These cities were chosen based on climate, demography and rate of urbanisation. The cloud free Landsat level 1 data sets are processed using numerical models developed by our research group. The LST intensity and its spatial and temporal variations during the summer season are appraised in this study. The statistically significant hot spot and cold spot regions were identified using Getis-Ord Gi statistical approach. The mean difference between LST estimated for the span of 25 years is showing positive trend and quantified as 10 °C, 11 °C, 18 °C, 11 °C and 13 °C in the case of Ahmedabad, Chennai, Delhi, Kolkata and Mumbai respectively. The relationship between LST and few surface characteristics is also studied. The result shows water bodies, soil moisture and greeneries plays a vital role in reducing both surface and air temperature considerably in the adjoining areas. The results of this study would help policy makers and urban planners to monitor and mitigate UHI effectively.

1. INTRODUCTION

The world is undergoing an unprecedented rate of urbanization (Cohen, 2006). About 70% of global energy is consumed in urban areas, which accounts for around 2% of the world's land surface (Omer, 2008). Energy consumption in urban areas correlates positively with changes in urban micro-climate which contribute to elevated air temperature in urban area compared to surrounding rural areas with the temperature differences being between 1 and 3 °C, this phenomenon is called Urban Heat Island (UHI).

1.1 Potential causes of Urban Heat Island

Urbanization plays a vital role in the formation of UHI. Increasing impervious surface, shrinking water bodies, decreasing vegetation cover are making cities vulnerable to UHI. The intensity of UHI effect depends on various factors including high building density, anthropogenic heat emission, air pollution, urban morphology and ecological features (Mihalakakou et al., 2004; Watson et al., 1991; Unger et al., 2001). The combined impact of heat waves (due to global impact) and the UHI (local phenomenon) possess *severe heat stress* on cities those are already under the impact of heat waves. Studies found that as the cities grow both frequency and intensity of urban heat waves are expected to increase.

1.2 Different layers of Urban Heat Island

Urban heat island can be observed at three different layers: canopy, surface and boundary (Oke, 2010). Surface Urban heat islands are having higher surface temperature in urban areas compared with surrounding rural regions which are generally illustrated with thermal images. Atmospheric heat islands have warmer air in urban areas compared with surrounding rural areas, which can be illustrated using isotherm maps or graphs. Atmospheric heat islands are again sub-divided into two layers such as canopy layer and boundary layer heat island. Canopy layer heat islands are present in the air layer where we live - from soil floor to the upper sides of trees or buildings. Boundary layer heat islands are in the area above rooftops and trees extending upwards as much as one mile. Long wave radiation has been bounced within the city without losing it to the atmosphere which leads to increase of atmospheric urban heat island which peaks at night time. Surface Urban Heat Island effect is there during day and night because of the heat capacity of materials used for pavements, buildings, roofs and so on (Rajgopal, 2014). This variation on temperature over the surface can be calculated using land surface temperature obtained from remote sensing technology.

UHI measurements are carried out in two different ways either by measuring air or surface temperature. Traditionally air temperature is measured using automated weather stations fixed at different locations. Several studies measured air temperature using hand held devise fixed at mobile vehicle to get thermograph of desired route/location. Remote sensing observation of air temperature based on statistical relationship attempted to establish between air and surface temperature isn't successful in daytime due to strong impact of insolation. The capability of measuring heat remotely limited only to surface skin temperature and it has directly used in several studies since the air and surface temperature has strong linear relationship. Surface temperature is measured using the satellite or airborne remote sensing data provides detailed thermography of the area of interest. In tropical cities summer time UHI shows peak intensity during night.

1.3 Selected UHI studies in India

India, the second most populous country with 1.2 billion people (August, 2001) is also expanding urbanization which leads to UHI effect. Rapid urbanization increases local temperature within cities whereas temperature in less built-up sub-urban/rural areas generally remain constant over the years. Many researchers have been studying Urban Heat Island effect of India, which is adversely affecting human lives.

In India Urban Heat Island research was first initiated by S Sundersingh in 1992 on Madras urban area using mobile observation. The proof of existence of UHI phenomenon in India was obtained using different physical factors data such as surface temperature, humidity and wind speed. A temperature profile was plotted using two observations which help to determine the existence of UHI effect in Madras urban region.

The measurement of LST are dependable upon the seasonal variation and day-night differences. From early 1900's after introducing earth observatory satellite, land surface temperature was calculated for Urban Heat Island studies. Large scale coverage of area was only obtained by satellite image. More, Kale, Garima, Rane, & Deshpande, 2015 studied different approaches for study Urban Heat Island in India. Mainly the study was divided into estimation of air temperature and surface temperature. Air temperature was estimated using data-Mobile Observations Approach and Surface temperature was calculated using Remote Sensing approach. Faris & Reddy, 2010 estimated the UHI of Chennai city. They found 12°C temperature difference within the Chennai city and surrounding area. The estimation was done using the LST calculation. The role of water body and vegetation cover has shown a great effect in cooling the surface. Goswami, Roy, & Sudhakar (2013) used G Statistics to identified hot spot and cold spot over Kamrup Metro District of Assam. The socio-economic data and biophysical parameters were added for identifying cause and future implication of UHI. The research result shown the linear impact of impervious surface for the increase of surface temperature.The studies conducted so far are having limited understating of temporal variation within cities for a longer time. This provides scope for understanding UHI intensity and its underlying causes for a long time.

1.4 Significance of the current study

This study aims to understand the spatio-temporal variations in urban heat island intensity of selected metropolitan cities in India during summer season for the period of 27 years (1988-2015). The number of UHI studies carried out on different cities in India has been growing rapidly over the years. The studies were mainly conducted to look at the hotspot over a specific period in general for a short period of time (usually managed with few Landsat scenes) however a longer observation wasn't carried out for cities in India. This study aims to fill the gap and studies all the cloud free and quality images available for download and analyzed. Further hotspots of different cities its size and intensity were also studied. Also, an attempt has been made to understand the spatial distribution of surface temperature over different land cover types such as water, built up land and vegetation. The present study examined the intensity of UHI over five selected Indian metropolitan cities (Ahmedabad, Chennai, Delhi, Kolkata and Mumbai)(figure 2) for the period 1981-2016. These cities were chosen based on climate, demography and rate of urbanization.

1.5 Data and tools

Cloud free Level-1 (geometric and radiometric corrected) Landsat satellite series (TM, ETM+, TIRS) images of the study areas were freely downloaded from Earth Explorer website (http://earthexplorer.usgs.gov/). The details about the downloaded scenes are compiled in table 1.

Table 1 Details of Landsat images used in this study

Study area	Latitude & Longitude (DD)	Path/Row	Spatial reference	Scenes used
Ahmedabad	23.0225 72.5714	148/44 149/44	WGS_1984_UTM_ZONE_44N	21
Chennai	13.0827 80.2707	142/51	WGS_1984_UTM_ZONE_44N	21

Delhi	28.6139 77.2090	147/40 146/40	WGS_1984_UTM_ZONE_43N	18
Kolkata	22.5726 88.3639	138/44	WGS_1984_UTM_ZONE_45N	20
Mumbai	19.0760 72.8777	148/47	WGS_1984_UTM_ZONE_43N	21

Though the revisit period of Landsat series is 16 days it is rare to get cloud free images of summer time image over the tropical cities. Fewer images (average 20 images available for the study period) are only available for the selected cities in last three decades. The downloaded Level-1 Landsat images were used as an input to the numerical models built on MATLAB by our research group, the models are capable of computing emissivity and land surface temperature using a simple GUI, user needs to specify directory in which the input images and metadata file are stored. Similarly output image are automatically stored inside the input directory. Further ARCGIS software is used to identify hotspots using Hot Spot Analysis (Getis-Ord Gi*) tool available in mapping cluster toolset. The post processing is also carried out in ARGGIS software.

2. METHODOLOGY

In this study LST is used as an indicator to understand UHI extent and its intensity. The methodology adopted is in line with Nithiyanandam & Nichol (2016), in which Land Surface Emissivity (LSE) is estimated using a novel method extracts emissivity values using reflectance in SWIR regime. This enables one to estimate LSE from the datasets of respective scenes without assigning constant values to objects on earth. Hotspot analysis is performed over individual scenes and the identified hotspots are compared with its underlying features. The major underlying features considered in this study are water bodies, buildup land and vegetation. The intensity of LST over three land cover types are analyzed by taking representative sample image of decades (i.e. one single image of a decade had been used to study the relation between UHI and identified underlying features. This study also examined the ideal size of grid to be used for performing effective LST-hotspot analysis of Indian cities. The detailed methodology is in figure 1.

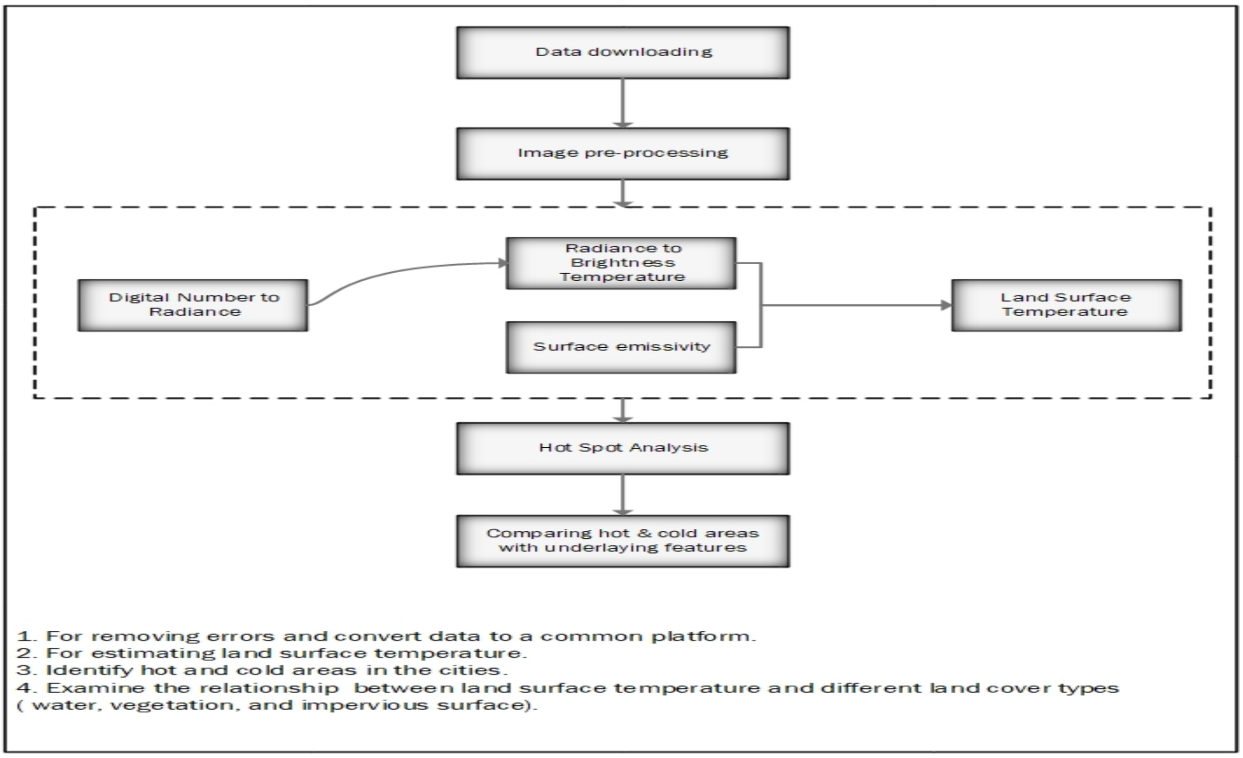

Figure 1: Methodology used in this study

3. RESULTS AND DISCUSSION

Surface temperature variation of cities are examined through100 m and 30 m gridded cells. It is evident that the 100 m grid cells are comparatively better to characterize the land surface temperature of Indian cities. This may due to the fact that the thermal infra-red bands in Landsat images is around 100 m, hence the temperature characterization can be well studied using 100 m. The extracted gridded cell values used to find statistically significant hot spots and cold spots within the city.

The study shows that the water bodies in the cities acts as a good mitigatory to heat sink followed by vegetation. The hotspots identified using 100 m and 30 m grid cells falls mostly on barren/open lands and buildup areas (impervious surfaces), this could be possible since the daytime (mostly captured between 10-11am in the morning) images are only accounted in this study. Studying night time images will provide overall picture about diurnal variation in land surface temperature emitted by different surface features. For example, open lands exposed to insolation warm and cool faster compared with water bodies which are slower in both the physical process due to thermal inertia of the material. Impervious surfaces possess has the property of absorbing incoming radiation to an extent and emits with a time delay mostly after sunset in the evening.

In case of Ahmedabad Sardar Vallabhbhai Patel Airport which was setup in 1937 and got activated from 1992 is identified as hotspot, this could be due to higher density of impervious surface and anthropogenic heat emissions in that zone. Water bodies such as Sabarmati river which flows across Ahmedabad, Kankaria lake which is artificially created by Qutb-ud-din Aybak situated at Maninagar, Saijpur lake are the cold spots. Lal Bahadur Shastri Stadium or Maleksaban was first sport stadium which was hot spot in early 2000's but later Ahmedabad Municipal Corporation was forced to convert the stadium into a lake front, eventually transforms that are into a cold zone. Sadly, the city do not own any big forest covers which helps to minimize the temperature of city to a greater extent. Singarva which is the census town and a cold spot in early 1990's has converted into a hot spot region in recent years. The series of hot spot maps generated for the city of Ahmadabad is in figure 3.

The city of Chennai is situated in the bank of Bay of Bengal. Beach sands (low thermal capacity) and open lands are in hotspot region whereas waterbodies (high thermal capacity) like lake and reservoirs are comparatively cooler. Velachery lake present in the south-east part of Chennai acts as a mitigating system for nearby hot spot regions. The sea breeze is another major factor in easing surface temperature many parts of the city. The Indian Institute of Technology Chennai campus is always a cold spot area because of the presence of vegetation cover throughout the campus. Hot spots are observed either over dense concrete buildup lands or open grounds. The urbanization and spread of UHI is inline each other. The series of hot spot maps generated for the city of Chennai is in figure 4.

The South-West part of Delhi is identified as hot spots in summer time images due to the existence of temporary fallow lands. Solar insolation at the time of image acquisition increases the intensity of land surface temperature due to low heat capacity of barren soil. Central parts of Delhi are comparatively cooler than other regions with the help of dense urban green space. River Yamuna influences its surrounding by minimizing air temperature by few degrees in its catchment area. Delhi and its surrounding has several micro climatic zones. The river Yamuna which passes through north east region of Delhi has the capacity to ease heat sink in nearby urbanized areas. Highly urbanized places like Dwarka are found to be hot throughout the study period. The intensity of hot spots are in increasing trend which may be due to the rapid urbanisation happening in the fringes and in many other parts. The series of hot spot maps generated for the city of Delhi is in figure 5.

Mumbai situated on the western coast of India has a tropical and dry climate. The open land and impervious surfaces are hotter and water bodies and places with green spaces are cooler like other cities. Almost it experiences similar impact of urbanisation on urban heat island. Any surface with high soil moisture is always cool and likely to radiate much after noon. The effect of humidity is not visible in images however it has affected the thermal comfort of people living extensively. The series of hot spot maps generated for the city of Mumbai is in figure 7.

Kolkata city is situated in the Basin of Bengal Tikiapara which is largely crowded slum area near railway station area is identified as hot spot over the years. Garden Reach situated in the south-eastern part of Kolkata and on the bank of Hooghly river is also hot spot region throughout the year. The presence of water bodies within the city influences surrounding areas up to few meters thus creates cold spots. Conversely, the barren lands in Kolkata are not hot unlike other cities due to its soil type and moisture content. The hotspots are commonly found over the impervious surfaces in Kolkata. The series of hot spot maps generated for the city of Kolkata is in figure 6.

The average temperature difference among impervious and non-impervious surface of Ahmedabad is 5-6 °C, in Chennai 3 °C, in Delhi 5-12 °C whereas in Kolkata about 3-4 °C and in Mumbai it is about 4-5 °C. Delhi shows high increase of built up area temperature above 40 °C followed by Ahmedabad, Mumbai, Chennai and Kolkata. Higher temperature over vegetation was observed in Ahmedabad (above 35 °C), followed by Delhi, Mumbai, Chennai and Kolkata. Incase of water bodies, highest average temperature was shown in Ahmedabad followed by Delhi, Chennai, Mumbai and Kolkata.

In some cases, the barren lands and built up are coming under the same category due to the similar emission in middle infrared that are used for the calculation of surface emissivity. Due to high heat emission Delhi shows high temperature (observed over barren lands) among all five cities. Uniquely Ahmedabad city has higher temperature in all land cover types where vegetation's average temperature is 34 °C and water bodies is 30 °C.

4. CONCLUSION

The average temperature of cities shows an increasing trend over the years. A necessary mitigation step along with planning for future must be undertaken by the officials and people to some extent in order to reduce rising surface temperature. Ahmedabad has drafted the first Heat Action Plan in 2013 to prepare against heat wave, similar action plans may be prepared for different cities after due consideration of the existing UHI situation and morphology of the city. Shirking lakes should be protected and efforts needs to be taken to increase vegetation cover in cities. Because evapotranspiration of vegetation helps to keep environment cool thus reduce impact of UHI. Urban local bodies should ensure the way for airflow between building and sufficient green spaces even before approval because wind flow helps to reduce heat sinks. The temporal changes in micro climate were clearly visible from hot spot analysis carried out using Getis-Ord Gi* statistics. The mean difference between LST estimated for the span of 25 years is showing positive trend and quantified as 10 °C, 11 °C, 18 °C, 11 °C and 13 °C in the case of Ahmedabad, Chennai, Delhi, Kolkata and Mumbai respectively. The clusters of hot and cold spots in the imagery were accurately mapped using this tool. The day time Landsat satellite images of cities have limitation to understand diurnal variation of UHI in the cities. Perhaps a comprehensive study by looking at both day and night time images are required to map the actual intensity during diurnal cycle and also to understand the behavior of surface objects with response to heat. These limitations provides way for the future research towards making Indian cities smarter and livable.

5. REFERENCE

August, Cxii. 2001. Quarterly Journal of Economics. Quarterly Journal of Economics. Vol. CXII.

Cohen, Barney. 2006. "Urbanization in Developing Countries: Current Trends, Future Projections, and Key Challenges for Sustainability." Technology in Society 28 (1–2): 63–80.

Mihalakakou, G., M. Santamouris, N. Papanikolaou, C. Cartalis, and A. Tsangrassoulis. 2004. "Simulation of the Urban Heat Island Phenomenon in Mediterranean Climates." Pure and Applied Geophysics 161 (2): 429–51.

Nithiyanandam, Y., and J. E. Nichol. 2016. "A Simple and Effective Retrieval of Land Surface Temperature Using a New Reflectance Based Emissivity Estimation Technique." International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives 41 (July): 443–47.

Oke, T R. 2010. "The Distinction between Canopy and Boundary - Layer Urban Heat Islands," no. April 2014: 37–41.

Omer, Abdeen Mustafa. 2008. "Energy, Environment and Sustainable Development." Renewable and Sustainable Energy Reviews 12 (9): 2265–2300.

Unger, János, Zoltán Sümeghy, and Judit Zoboki. 2001. "Temperature Cross-Section Features in an Urban Area." Atmospheric Research 58 (2): 117–27.

Watson, I D, T R Oke, and G T Johnson. 1991. "Conditions Part 2: Diagnosis," 339–58.

6. APPENDIX

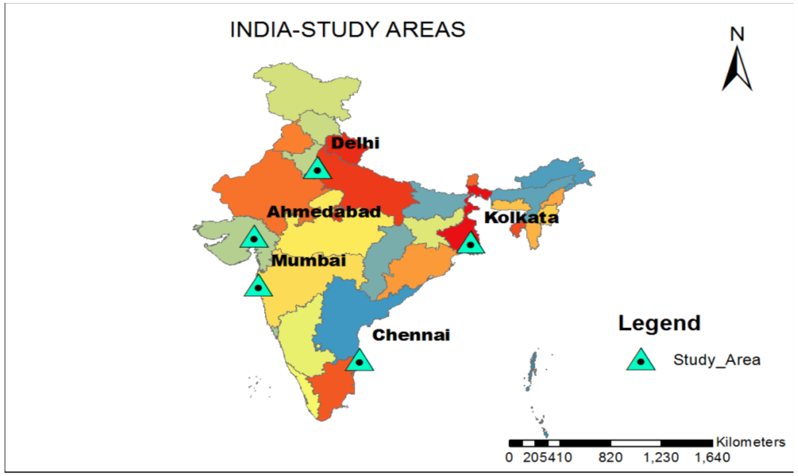

Figure 2: Study Area

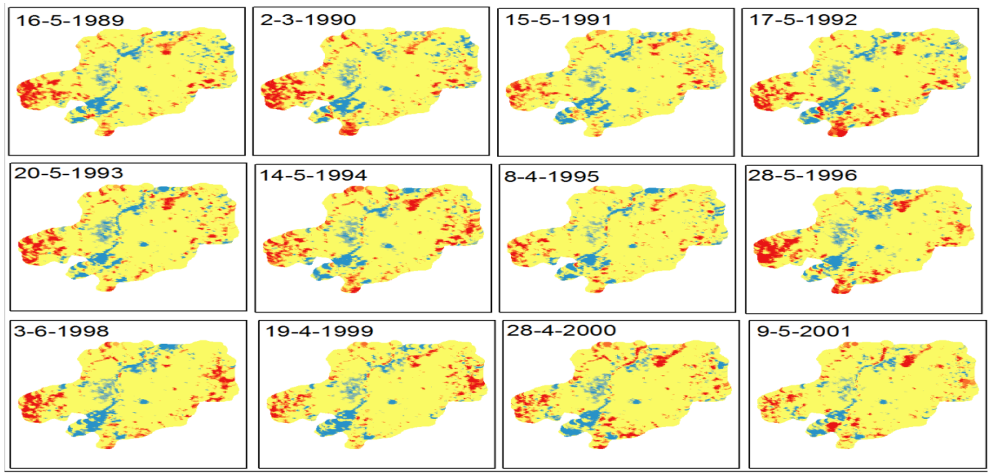

Figure 3: Hotspot Analysis for Ahamadabad

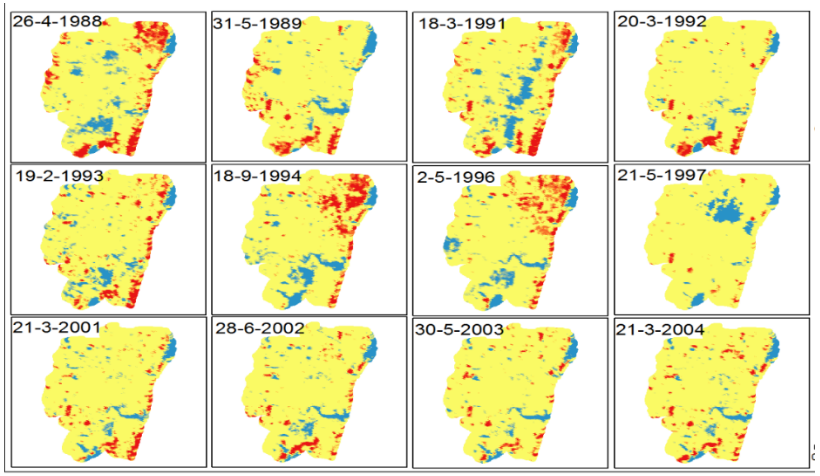

Figure 4: Hotspot Analysis for Chennai

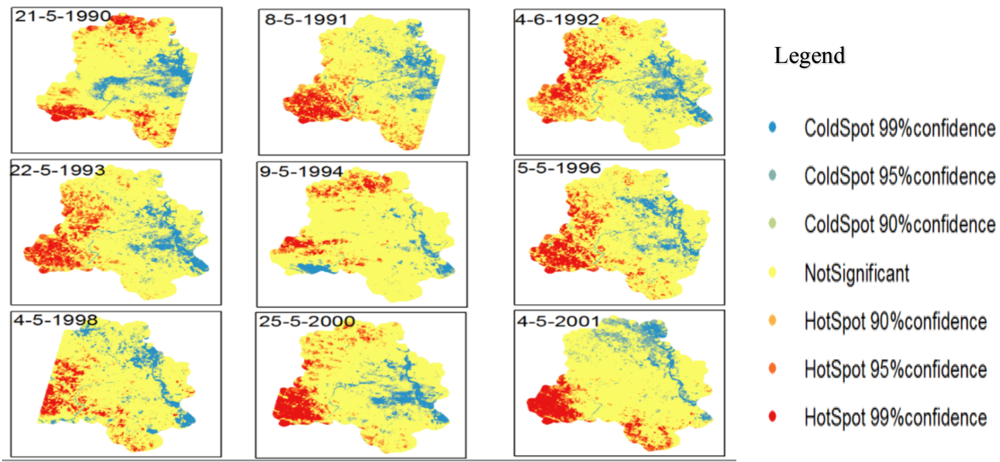

Figure 5: Hotspot Analysis for Delhi

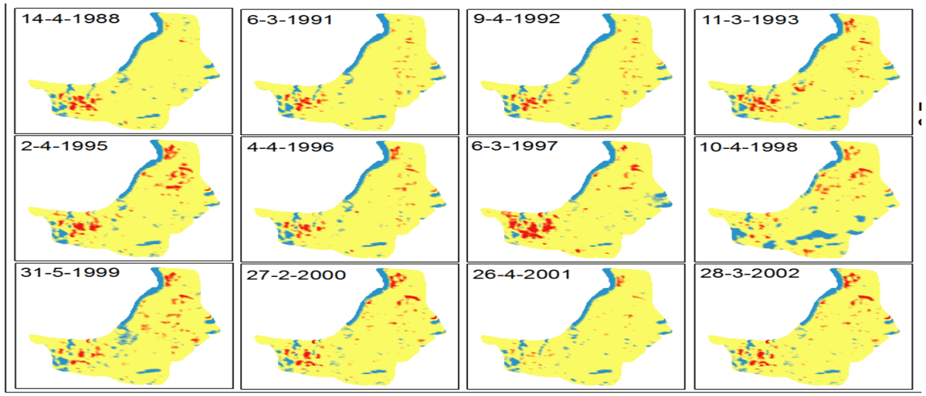

Figure 6: Hotspot Analysis for Kolkata

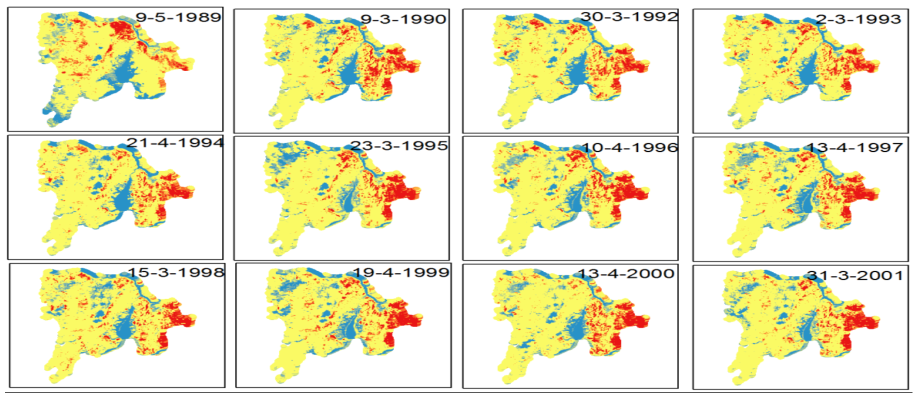

Figure 7: Hotspot Analysis for Mumbai