Ind. J. of Landscape Systems and Ecological Studies **43** (1) March - 2020, 82- 98 **ISSN 0971-4170**

Geo-Spatial Analysis of Alteration in Urban Biophysical Composition and Its Impact on Micro-Climate of Delhi, India

Sandesh Yadav*

Abstract : *The increased infrastructural and economic growths have raised issues of micro-climatic changes in the national capital territory of Delhi, India. In this paper, the land surface biophysical types, land surface temperature and vegetation indices retrieved from Landsat thematic mapper, enhanced thematic mapper and operational land imager images of Delhi for 1990, 2000 and 2015 were analyzed. The images acquired were classified into appropriate land cover types using a supervised classification scheme and a change detection analysis was carried out on the classified images to evaluate the extent of modification of surface features. A quantitative approach was used to explore the relationship among temperature, surface biophysical components and vegetation indices. Results showed that impervious surfaces (built-up) were positively correlated with high land surface temperatures. Conversely, vegetated areas and land surface temperatures have strong negative correlation.*

Keywords : *Surface biophysical components, Land surface temperature, Surface thermal response, Normalized difference vegetation index*

Introduction

Industrialization and urbanization have increased the anthropogenic stress on land use/land cover to meet the demand of space for emerging settlements due to ever increasing human population. Urbanization altered the landscape, so land transformed from natural land to anthropogenic surfaces viz. commercial, industrial, transportation and residential lands. Thus, impervious surfaces came into scene and modification has taken place in terms of surface energy exchange and anthropogenic heat discharge. Consequently, there is an increase in land surface temperature which significantly alters the micro-climate of any urban region. The alteration in micro-climate can be seen in terms of urban heat island (UHI) effect, winter warming effect and heat wave intensification.

Land surface temperature is a key parameter in land surface processes and acts as an important function of land use/land cover. In addition, land surface temperature plays a major role in evaporation

* *Freelance Researcher, New Delhi, India, Email: sandesh_official@yahoo.in*

models, climate models and radiative transfer models. The presence of healthy vegetative cover regulates the land surface temperature through cooling effect due to evapotranspiration.

Objectives of the Study

- To analyze the dynamics of urban biophysical composition (1990-2015) in the NCT of Delhi.
- To assess the impact of altered urban biophysical composition on the micro-climate with special reference to land surface temperature and normalized difference vegetation index (1990-2015) in the study area.

Database and Methodology

The study looks at the city of Delhi, national capital of India (Figure 1) due to its high degree of urbanization, dominant grey infrastructure and high density of population. It is located between the latitude 28°24´17´´ N and 28°53´00´´ N and longitude 76°50´2´´ E and 77°20´37´´ E. It has an area of about 1483 km^2 with maximum length of 51.90 km and maximum width of 48.48 km. The study employs Landsat-4,5 TM for 7 November 1990; Landsat-7 ETM+ for 16 November 2000 and Landsat-8 OLI for 9 November 2015 (see Table 1). All imageries were obtained from the archives of United States Geological Survey (USGS). The Three scenes fell within the path 147 and row 40 of the WRS-2 (Worldwide Reference System) from which the data for the location under the study could be extracted. All bands 1-5 and 7 have spatial resolution of 30 m and the thermal infrared band (band 6) has a spatial resolution of 60m for Landsat 7 and 120m for Landsat 5. For Landsat OLI, thermal infrared band (10,11) has a spatial resolution of 100m.

Table- 1. Landsat meta-data for the study area

City	Path/Row	Satellite Platform	Band		Date Acquired	Resolution
			Spectral	Thermal		
Delhi	*147/40*	Landsat-4,5 TM	1-5 & 7	6	07/11/1990	30m/120m
		Landsat-7 ETM+	1-5 & 7, 8	6	16/11/2000	30m/60m
		Landsat-8 OLI	1-9	10, 11	09/11/2015	30m/100m

Source: United States Geological Survey, 2016

Data Sources

The satellite images of the NCT of Delhi for three different periods that is 1990, 2000, 2015 were obtained from the United States Geological Survey (USGS) and National Remote Sensing Centre (NRSC), Hyderabad, India.

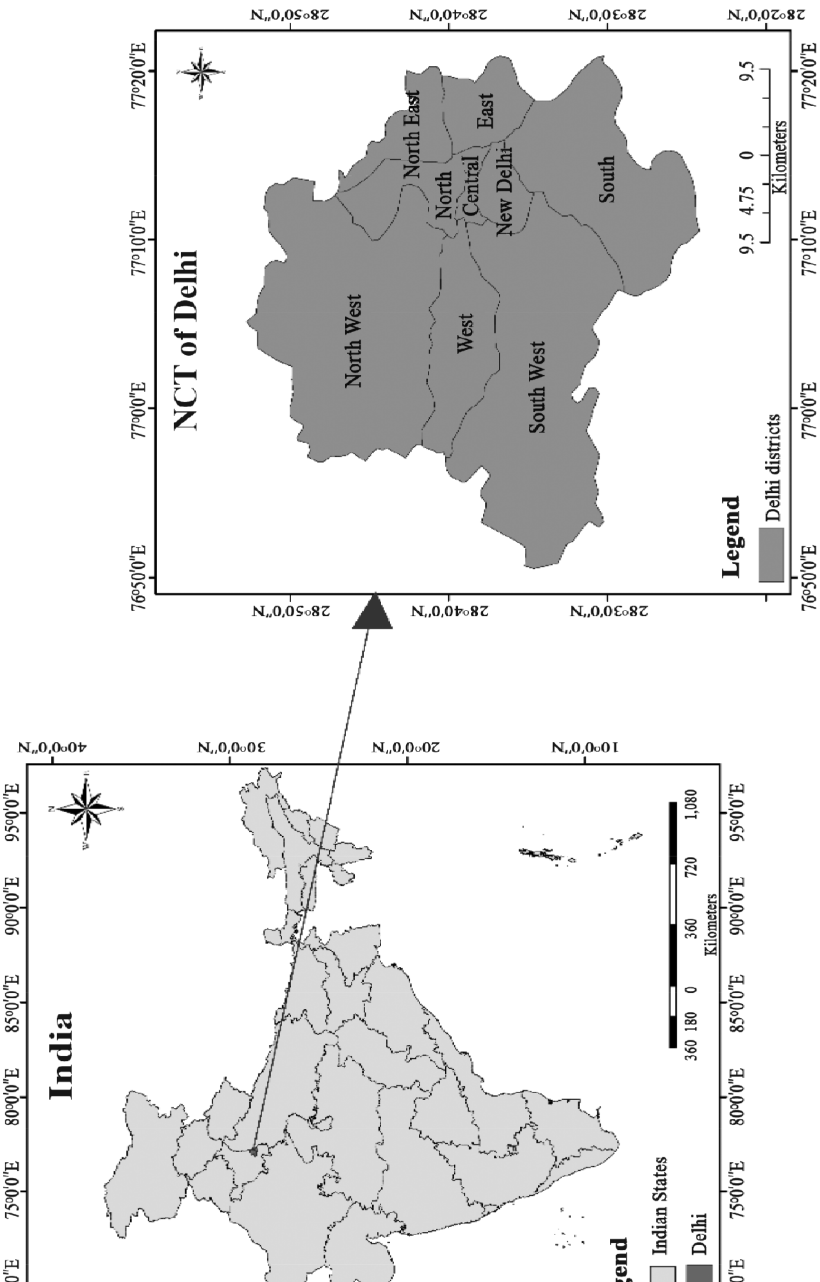


Figure 1. Location map of the study area.

Tools of Analysis

To calculate the 'rate of change per year', formula given byChebet(2013) was used:

$$R = \frac{Y - X}{T}$$

Where, R = rate of change, Y = the area (km^2) of the study area in the final year, X = the area (km^2) of the study area in the initial year, T = the time difference in years.

A three-step process was followed to derive surface temperature from Landsat TM 7 Image.

Step-1: Spectral radiance was calculated using following equation:

$$L = LMIN + (LMAX - LMIN) \times DN / 255$$

Where, L = Spectral Radiance, LMIN = 1.238, LMAX = 15.600, DN = Digital Number.

Step-2: Spectral Radiance (L) to Temperature in Kelvin may be expressed as:

$$T_B = \frac{K_2}{ln\left(\frac{K_1}{L} + 1\right)}$$

Where, K_1 = Calibration Constant 1 (607.76), K_2 = Calibration Constant 1 (1260.56), T_B = Surface Temperature

Step-3: Surface temperature from Lands at 8 TIRS was derived using band 10 and 11 following the split-window method first proposed by McMillin(1975).

The algorithm is:

$$LST = TB_{10} + C_1(TB_{10} - TB_{11}) + C_2(TB_{10} - TB_{11})2 + C_0 + (C_3 + C_4W)(1 - \varepsilon) + (C_5 + C_6W)\Delta\varepsilon$$

Where, LST = Land Surface Temperature, C_0-C_6 = Split Window Coefficient Values, TB_{10} = Brightness Temperature of Band 10, TB_{11} = Brightness Temperature of Band 10, ε = M band 10 and 11, ε = Mean LSE of TIR Bands, W = Atmospheric Water Vapor Content and Δε = Difference in LSE.

To calculate the 'Normalized Difference Vegetation Index (NDVI)', we will use the following formula:

$$NDVI = (NIR - Red) / (NIR + Red)$$

Where, Red and NIR stand for the spectral reflectance measurements acquired in the Red and Near Infra-Red (NIR) regions respectively. NDVI itself thus varies between —1.0 and +1.0.

Table- 2. Details of land use/land cover types

Land use/land cover types	Description
Water body	It refers to oceans, seas and lakes along with ponds, wetland and even puddles. In addition to this, rivers, streams, canals (water moves from one place to another) are also considered bodies of water. Broadly it includes river, permanent open water, lakes, ponds, canals, permanent/seasonal wetlands, low lying areas, marshy land and swamps.
Vegetation	It is an area notified for forestry boundary, predominantly with trees and other vegetation capable of producing either timber or other forest produce. Broadly it includes trees, natural vegetation, mixed forest, gardens, parks and playgrounds, grasslands, vegetated lands.
Cropland	It is defined as the land primarily used for farming and production of food crops, commercial crops and horticulture crops. It includes the land under irrigation and rain-fed crops, which are growing under different seasons in different farming activities.
Fallow land	Fallow is the stage of crop rotation in which the land is deliberately not used to raise a crop.It may refer to stream bed, the channel bottom of a stream or river or creek, Wadi, a dry riverbed that contains water only during times of heavy rain.
Riverbed Built-up	It is a term used primarily in urban planning, real estate development, building and the construction industry. Broadly it includes residential, commercial, mixed use and industrial surface areas, asphalt road network, pavements, rocks, parking lots and other man-made structures.

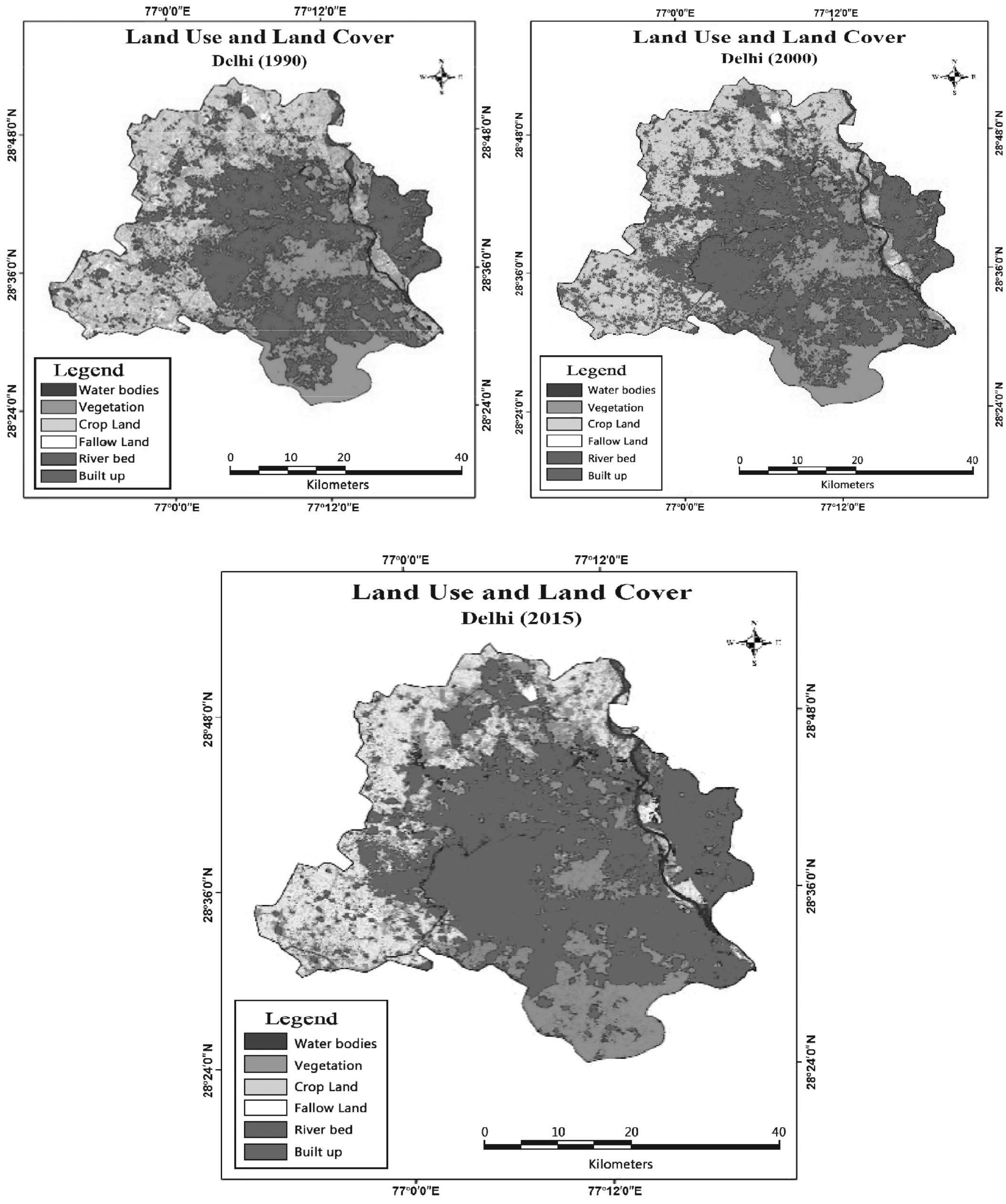
Source: National Remote Sensing Agency Manual (2006), NRSA, Hyderabad, India

Results and Discussions

Land use/land cover changes during the period 1990-2015

Before carrying out the interpretation of maps, we need to understand the colour scheme adopted in the maps (Figure 2) to understand the changes in land use/land cover during the period 1990-2015 in the study area. As per the colour scheme, the water body and vegetation cover are depicted by their natural colours that is blue and green respectively while built-up and cropland are depicted by red and yellow colour respectively. The other categories viz. Fallow land and barren land are represented by pink and magenta colour respectively.

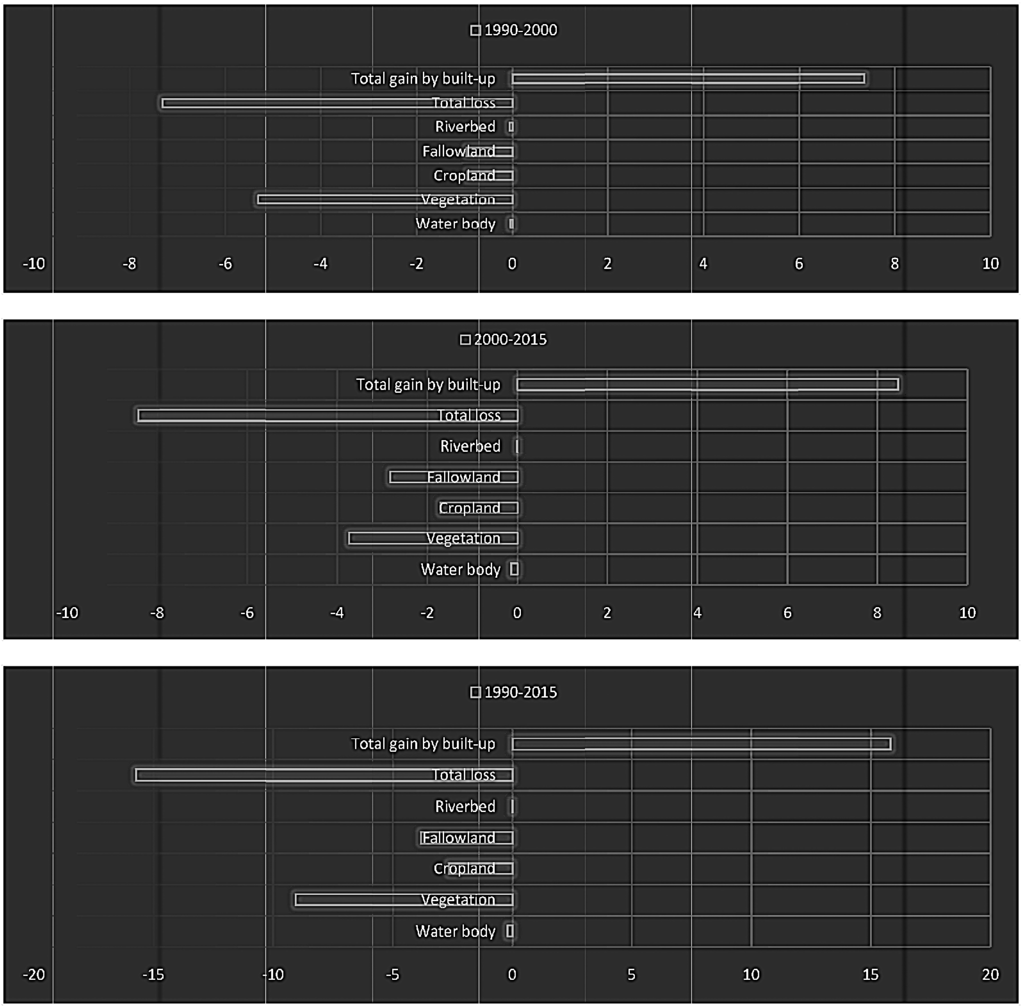
The prevalence of red colour on the LULC map of 1990 shows the dominance of built-up with variations in built-up density at the core and peripheral regions of the study area. At the core, northern part, north-eastern part, eastern part, south-eastern part, southern part and north-western part are regions of high built-up density while on the other hand; the rarefied concentration of the built-up exists in the peripheral areas of the northern part, south-eastern part, south-western part,



Source: *Landsat Imagery, 7th November 1990, 16th November 2000 and 9th November 2015.*

Figure 2. Land Use and Land Cover, 1990, 2000 and 2015, NCT of Delhi, India

western part and north-western part of the study area. The LULC category of cropland has its limits in peripheral areas of northern part, south-western part and north-western part of the study area. The vegetation coverwas present in the core and peripheral areas of the eastern part and south-eastern part of the study area. The fallow land has been seen in the peripheral areas of the northern part, south-western part and north-western part of the study area. The LULC map for the year 2000 confirms an increase in the density of built-up both at the core and periphery of the study area. During the period 1990-2000, the built-up expansion took place in the south-eastern part, south-western part, western part and north-western part of the periphery while the built-up became denser



(a)

(b)

(c)

Figure 3. Gains and losses in land cover areas between (a) 1990-2000, (b) 2000-2015, (c) 1990-2015

at the core of the study area. The LULC map for the year 2015 shows shrinkage in the areal expansion of cropland, vegetation cover and fallow land due to built-up expansion. During the period 2000-2015, the cropland experienced a slight decrease in area in the peripheral parts of south-western part, western part and north-western part of the study area. On the other hand, the vegetation cover got reduced in the area drastically with huge losses at the periphery of the study area.

Table 3. Size and proportions, trend, and magnitude of LULC, 1990-2015, NCT of Delhi, India

LULC Classes	1990		2000		2015		1990-2000	2000-2015
	Hectares	%	Hectares	%	Hectares	%	%	%
Water Bodies	1899.4	1.3	1819.8	1.2	1583	1.1	-0.05	-0.15
Vegetation	26402.8	30.4	37225.5	25.1	31675.3	21.3	-5.31	-3.73
Cropland	45118.8	17.8	25012.4	16.9	22468.7	15.1	-0.936	-1.71
Fallow land	10980.9	7.4	9519.6	6.4	5308.0	3.6	-0.989	-2.83
Riverbed	1114.4	0.8	1016.2	0.7	1001.9	0.68	-0.066	-0.009
Built-up	62897.3	42.4	73819.5	49.7	86375.6	58.2	+7.539	+8.46

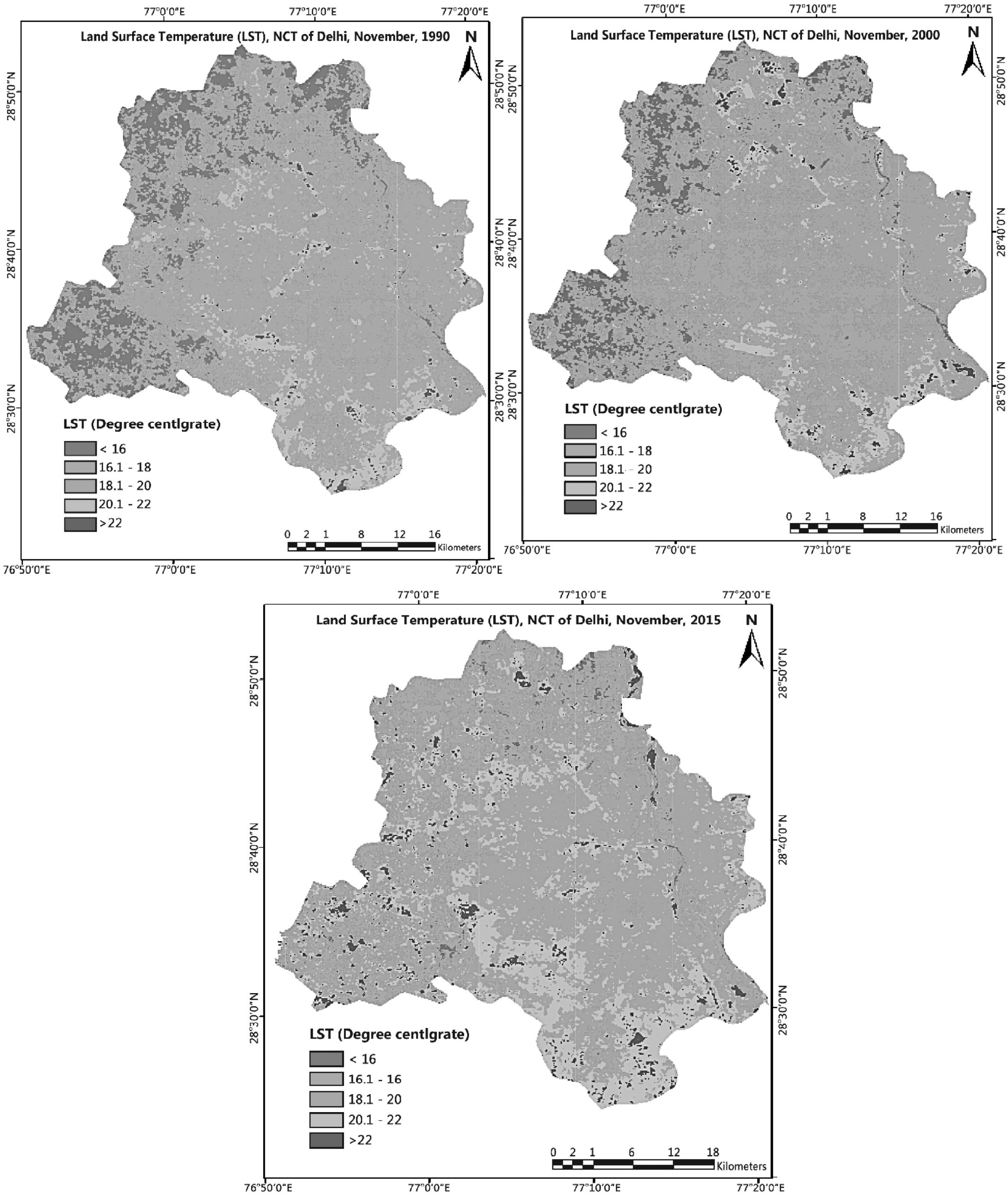
Source: Calculated and compiled by the scholar from Lands at imagery of 1990, 2000 and 2015

The study area has an area of 1,48,413.0 hectare (Table 3). The categories occupying major share include built-up area (42.4%), vegetation (30.4%), cropland (17.8%) while the minor share occupying categories include fallow land (7.4%), water bodies (1.3%) and riverbed (0.8%). During the period 1990-2000, built-up experienced tremendous increase from 42.4% (1990) to 49.7% (2000).These categories include vegetation [30.4% (1990) and 25.1 (2000)], crop land [17.8% (1990) and 16.9% (2000)], fallow land [7.4% (1990) and 6.4% (2000)], river bed [0.8% (1990) and 0.7% (2000)] and water bodies [1.3% (1999) and 1.2% (2000)]. During the period 2000-2015, the similar trend was observed in land use/land cover changes. The built-up showed drastic increase in its area while the other categories (except river bed) followed similar declining trend as in the year 2000. Consequently, the built-up increased from 49.7% (2000) to 58.2% (2015) and the categories which experienced decline in area includes water bodies [1.2% (2000) and 1.1% (2015)], vegetation [25.1% (2000) and 21.3% (2015)], fallow land [6.4% (2000) and 3.6% (2015)]. Riverbed [0.7% (2000 and 2015)] did not went any change.

Spatio-temporal Analysis of Urban Surface Biophysical Component

The spatial distribution of land surface temperature (Figure 4) five different temperature zones have been taken viz. <16ºC, 16.1-18ºC, 18.1-20ºC, 20.1-22ºC and >22ºC.

The LST map of 1990 shows that major part of the study area except for the peripheral regions in the extreme south-west, western region, north-west region and northern region lies in the temperature zone of 18.1-20ºC followed by temperature zones of 16.1-18ºC and <16ºC in the extreme



November 1990, 16th November 2000 and 9thNovember 2015

Figure-4. Land Surface Temperature (LST), NCT of Delhi, November 1990, 2000 and 2015

south-west, western region, north-west region and northern region at the periphery. The temperature zone of 20.1-22ºC covered area in the northern region, north-east region, eastern region, south-east region, southern region, south-west and western region of the study area. The temperature zone of >22ºC was not prevalent due to the presence of considerable vegetation cover and confined nature of built-up.

The LST map of 2000 shows that temperature zone of 16.1-18ºC becomes more prevalent in the peripheral regions and core regions of the study area. This temperature zone has acquired regions that were earlier under the temperature zones of <16ºC and were located in the northern, north-eastern, south-western regions at the periphery of the study area. Likewise, with the built-up expansion, the temperature zone of 20.1-22ºC have become prevalent in northern part, north-eastern, eastern part, south-eastern part, southern part, south-western part and north-western part in the peripheral regions of the study area. The other high temperature zone >22ºC have also become prevalent in the north, north-eastern, south-eastern and southern parts of the study area.

The LST map of 2015 shows that temperature zones of >22ºC, 20.1-22ºC, 18.1-20ºC have become more prevalent in the study area. The temperature zone of <16ºC was almost absent while the temperature zone of 16.1-18ºC have experienced shrinkage in the region due to destruction of vegetation cover and built-up expansion. The temperature zone of >22ºC have become prevalent confirming the rise in the land surface temperature during the period 1990-2015 in the study area.

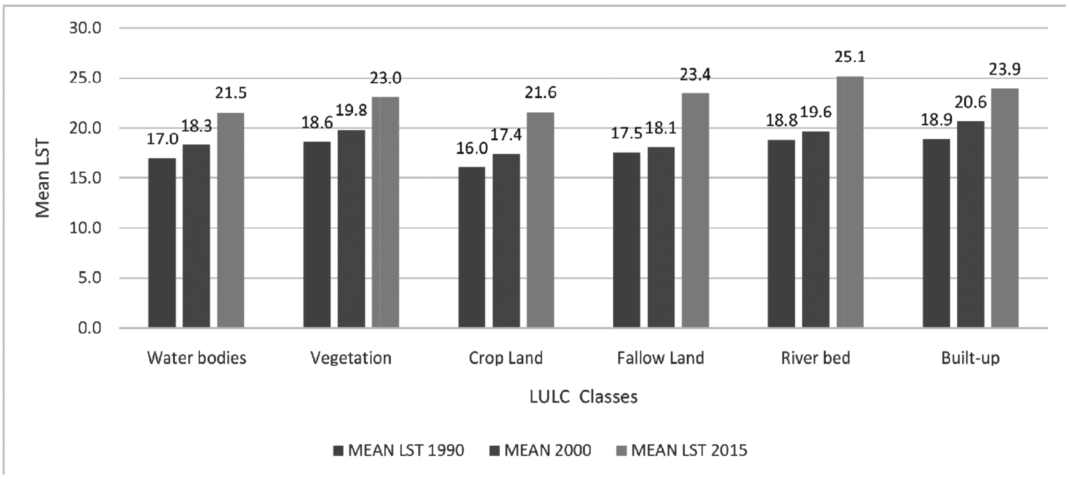


Figure- 5. Mean values of land surface temperature during 1990, 2000, 2015

The mean values of land surface temperature (LST_{mean}) have shown an increasing trend. Water bodies show an increase from 17.65°C (1990) to 18.30°C (2000) confirming the slight increase of 0.65°C while 18.30°C (2000) to 23.0°C (2015) showing an increase of 3.2°C. The overall increase in LST_{mean} was about 3.85°C during the period of 1990-2015.The vegetation cover shows an increase from 18.60°C (1990) to 19.60°C (2000) confirming the slight increase of 1.0°C while 19.60°C (2000) to 23.0°C (2015) showing an increase of 3.4°C. The overall increase in LST_{mean} was about 4.4°C during the period of 1990-2015.The cropland shows an increase from 16.0°C (1990) to 17.85°C (2000) confirming the slight increase of 1.85°C while 17.85°C (2000) to 21.60°C (2015) showing the tremendous increase of 3.75°C. The overall increase in LST_{mean} was about 5.6°C during the period of 1990-2015.The fallow land shows an increase from 17.50°C (1990) to 19.60°C (2000) confirming the slight increase of 2.1°C while 19.60°C (2000) to 23.4°C (2015) showing the tremendous increase of 3.8°C. The overall increase in LST_{mean} was about 5.9°C during the period of 1990-2015.The riverbed shows an increase from 18.80°C (1990) to 19.60°C (2000) confirming the slight increase of 0.8°C while 19.60°C (2000) to 25.11°C (2015) showing the tremendous increase of 5.5°C. The overall increase in LST_{mean} was about 6.3°C during the period of 1990-2015. The built-up shows an increase from 18.90°C (1990) to 20.70°C (2000) confirming the slight increase of 1.8°C while20.70°C (2000) to 23.9°C (2015) showing the tremendous increase of 3.2°C. The overall increase in LST_{mean} was about 5.0°C during the period of 1990-2015.

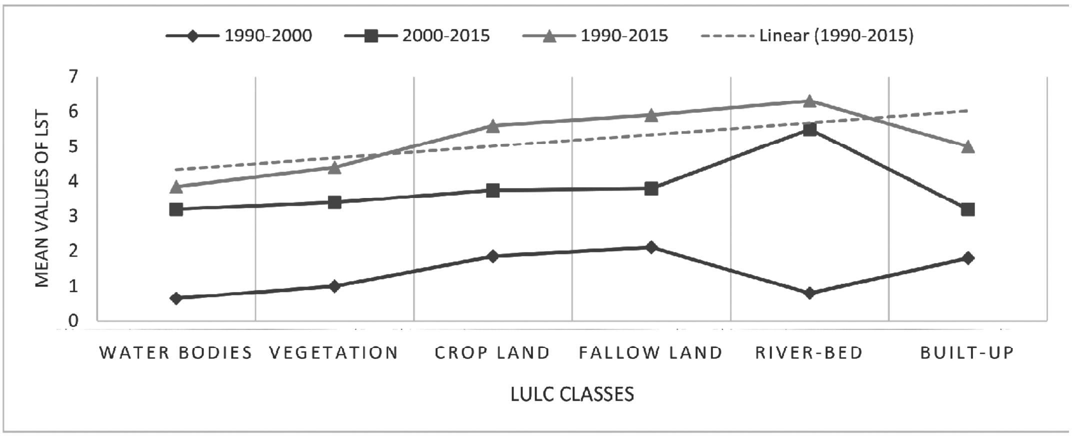
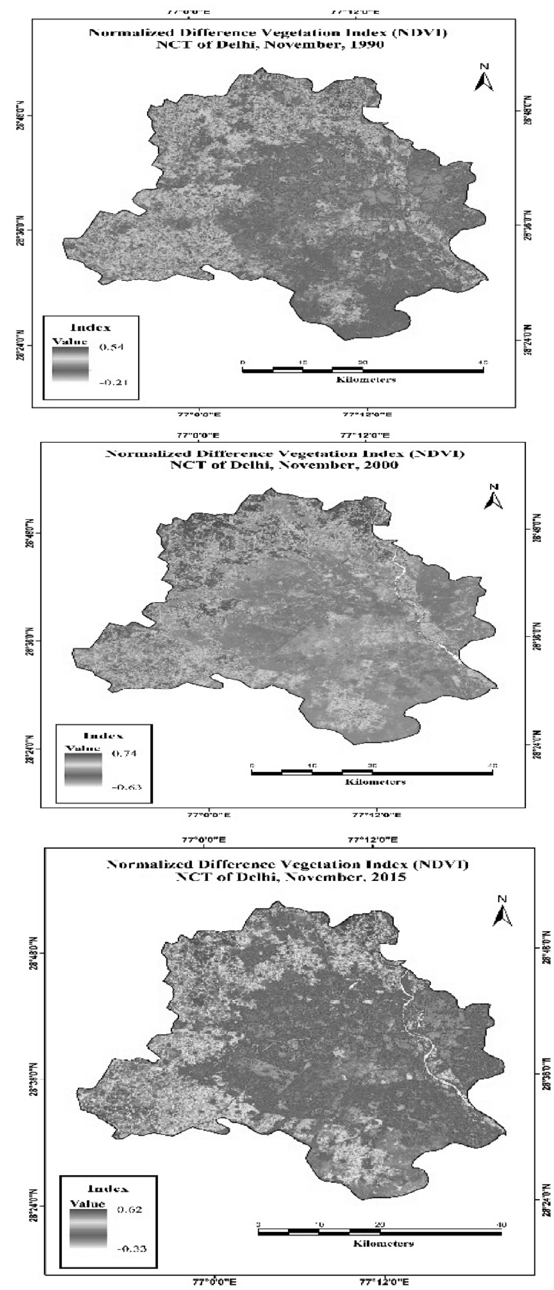


Figure 6. Differences in mean values of land surface temperature during 1990-2000, 2000-2015, 1990-2015

Quantitative Relationship between NDVI and Land Surface Temperature

The relationship between the vegetation and land surface temperature (LST) is 'inverse' in nature. This can be explained in terms of 'cooling effect' due to available healthy vegetation. The region with the availability of green healthy vegetation are characterized by the high rate of evapo-transpiration which adds moisture to the surrounding air making it cool air by extracting heat and consequently producing 'cooling effect' and this cooling effect regulates the atmospheric temperature. Moreover, available green vegetation also serves as a hindrance in the path of incoming solar radiation and thus, results in reduced heating of the ground surface.



Source:Landsat Imagery, 7th November 1990, 16th November 2000 and 9th November 2015

Figure 7. Normalized Difference Vegetation Index, NCT of Delhi, November 1990, 2000 and 2015

During the year 1990 (Figure 7), the healthy vegetation was at the periphery while the non-vegetated cover dominant at the core of the study area. During the period 1990-2000, the expansion of built-up took place in the peripheral regions marking the growth of non-vegetated cover in the study area. Likewise, during the period 2000-2015, urbanization catalyzed the pace of built-up expansion which resulted in vegetation destruction in the peripheral regions of the study area. Moreover, a strip of yellow colour shows that unhealthy vegetation is present around the non-vegetated cover.

Figure 8 shows the correlation (pixel by pixel) between LST with NDVI for the study area. LST has a negative correlation with NDVI (vegetation cover). This means wherever there is high NDVI the surface temperature is low and vice versa.

Table 4. NDVI and LST relationship for 1990, 2000 and 2015 in the NCT of Delhi, India

Years	R^2	P value	S value
1990	0.822**	0.73*	0.73*
2000	0.834*	0.86*	0.86*
2015	0.885**	0.91	0.91*

Source: Calculated and Compiled by the scholar

Note: P = Pearson, S = Spearman; (*)Regression analysis significant with an α = 0.1; (**) Regression analysis significant with an α<0.5

A close relationship was found between land surface temperature andthe normalized difference vegetation index (R^2>0.8). For the period 1990-2015, Pearson and Spearman indexes were higher than 0.7 and ranged from 0.72 to 0.92 and 0.73 to 0.91 respectively and thus, both statistical correlation measures demonstratea relation between LST and NDVI. This can be explained in terms of vegetation and thus NDVI could be used as an indicator of LST variability. In areas with vegetation cover, the radiative temperature registered by the satellite sensor has been found to better approximate the in-situ temperature. Vegetation cover also shows high temperature variations since thermal responses depend on the biophysical characteristics of the different species. This was observed in the NCT of Delhi where the urban vegetation (UV) land cover presented the highest variability. However, it is worth highlighting that LST is affected by urban expansion and that vegetation is considered an important mitigation factor of urban heat island intensity.

Impact on Micro-climate of the Study Area

The alteration in biophysical components due to urbanization hasa cascading impact on factors governing micro-climate viz. local energy budget, local wind movement, local hydro-logical cycle and thus, altering the micro-climate of the study area. In case of NCT of Delhi, the urban heat island effect is the main cause of micro-climatic changes. The fast pace of urbanization and related

(a)

(b)

(c)

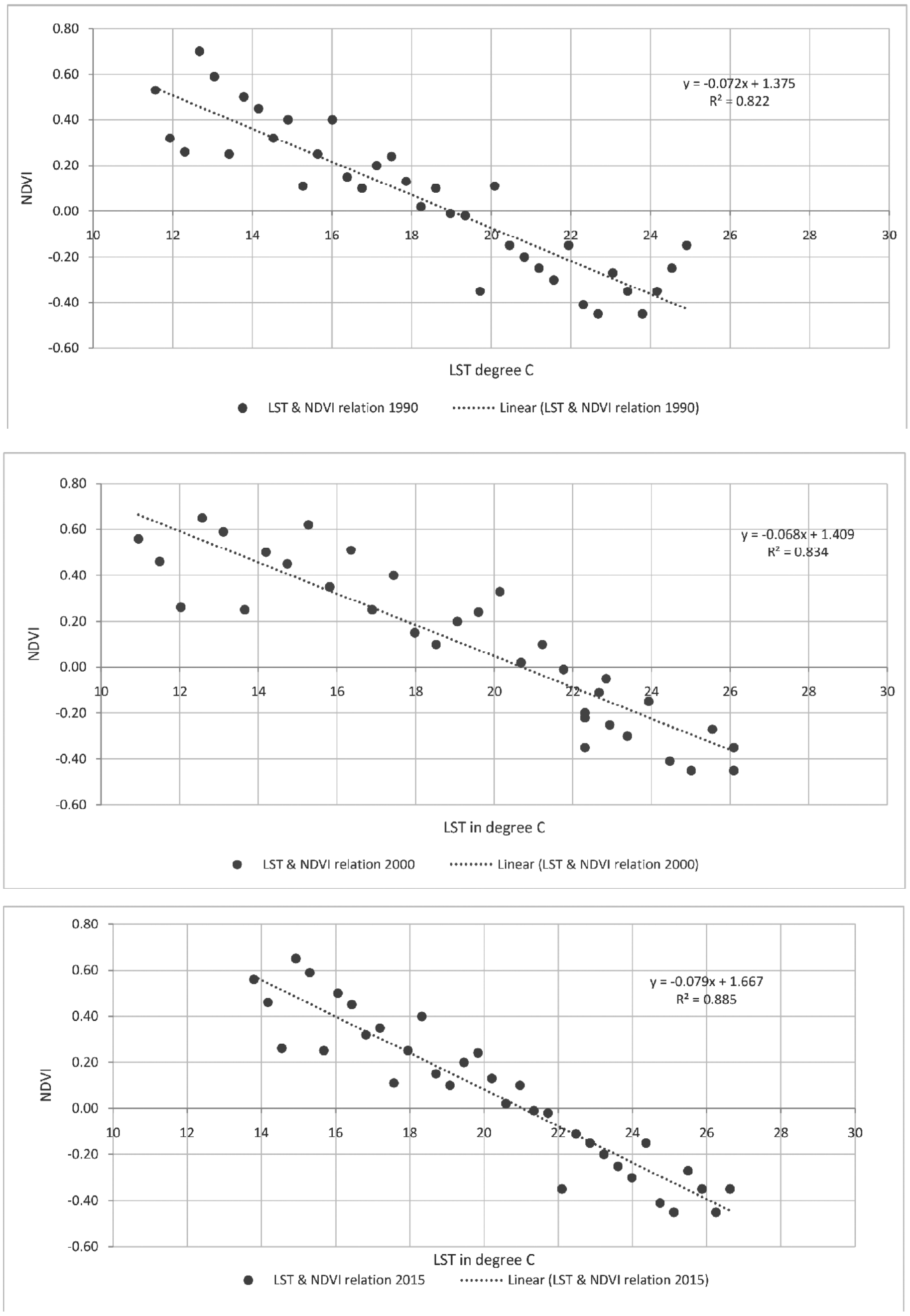
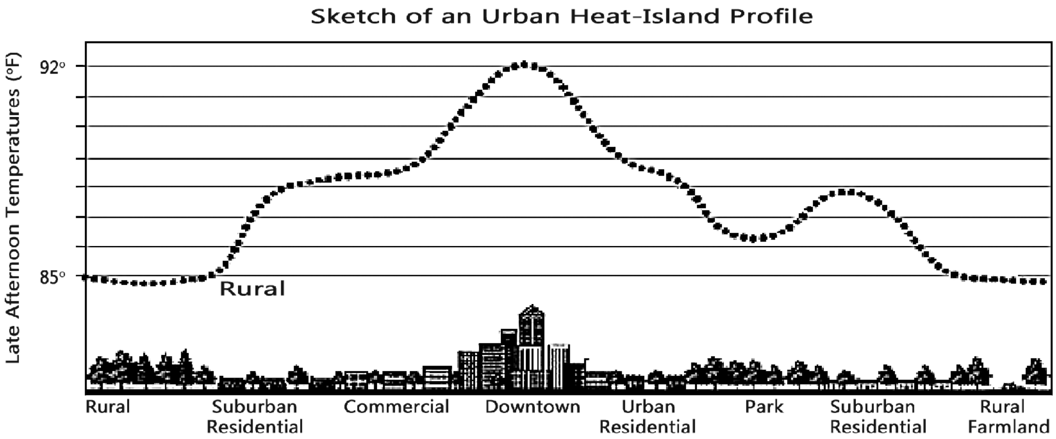


Figure- 8. Scatter plot NDVI and LST relationship during (a) 1990 (b) 2000 (c) 2015



Source: https://weather.msfc.nasa.gov/urban/urban_heat_island.html

Figure 9: Urban heat island profile

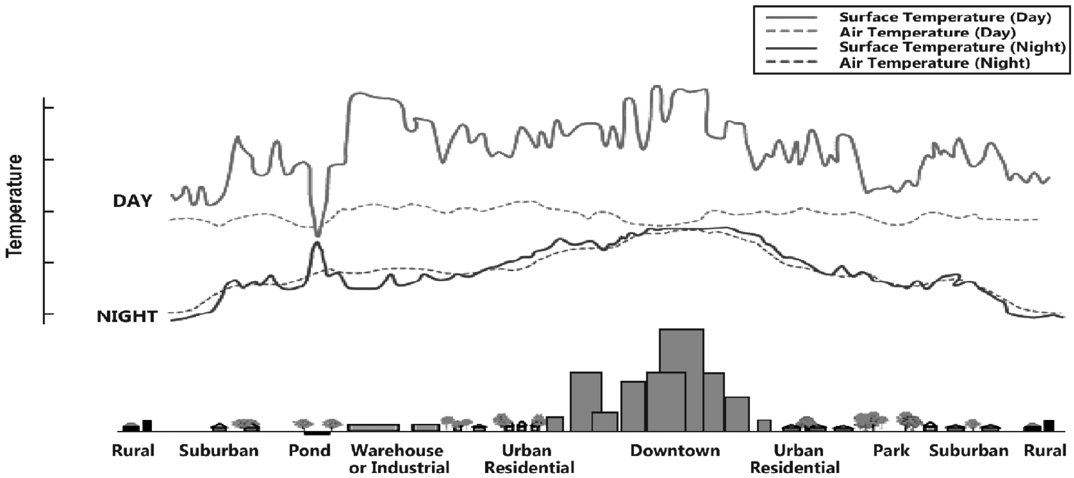
developmental processes have resulted in a reduction in vegetation cover and expansion of impermeable and dry surfaces. Thus, urban heat island came into existence with a warmer core and comparatively cooler periphery in the study area. The absorption of incoming solar radiations during day time and emission of infrared radiations from impermeable surfaces makes the core hotter and attains the temperature of 27-50ºC while surroundings remain close to air temperatures. Chandler and Lombardo identified the possible causes of urban heat island effect viz. energy transfers, reduced evapo-transpiration (vegetation destruction) and energy production from anthropogenic sources (impermeable surfaces). Further, Voogt classified urban heat islands into three categories based on their location and impact viz. Canopy layer heat island (CLHI), boundary

Table 5. NCT of Delhi: Overall mean values of LST and NDVI, 1990-2015

S. No.	LULC Class	ΣLST_{mean} (1990, 2000, 2015)	$\Sigma NDVI_{mean}$ (1990, 2000, 2015)
1	Water bodies	18.93	-0.03
2	Vegetation	20.48	0.53
3	Cropland	18.35	0.21
4	Fallow land	19.66	0.29
5	Riverbed	21.20	0.19
6	Built-up	21.15	0.32

Source: Calculated and compiled by the scholar from Landsat imagery 1990, 2000 and 2015.

layer heat island (BLHI) and surface heat island (SHI). The present research study discusses the surface heat island effect in the study area.



Source: https://ppreymond.weebly.com/urban-heat-islands-activity.html

Figure 10. Land surface temperature (LST) variations during day and night

Here, the changes in surface heat island (SHI) effect have been explained in the light of land surface temperature, land use/land cover changes and normalized difference vegetation index for the period 1990-2015. The land area under built-up increased from 62897.3 hectares (1990) to 86375.6 (2015) while the vegetation decreased from 45118.3 hectares (1990) to 31675.3 (2015) confirming the expansion of Grey infrastructure and destruction of vegetation cover. An increase in LST_{mean} temperature (1990-2015) for various categories of land use/land cover viz. water bodies [17.65°C (1990) to 21.5°C (2015)], vegetation [18.60°C (1990) to 23.0°C (2015)], crop land [16.00°C (1990) to 21.6°C (2015)], fallow land [17.50°C (1990) to 23.4°C (2015)], river bed [18.80°C (1990) to 25.1°C (2015)] and built-up [18.90°C (1990) to 23.9°C (2015)]. In other words, the LST_{mean} temperature during the period 1990-2015 increased by +3.85°C (water bodies), +4.40°C (vegetation), +5.60°C (crop land), +5.90°C (fallow land), +6.30°C (riverbed), +5.00°C (built-up) and thus, intensifying the Urban Heat Island (UHI) effect.

Conclusion

The metropolitan cities are characterized by the major portion of land under built-up and minor portion of land under vegetation and consequently facing micro-climatic changes. For example, NCT of Delhi, Kolkata, Bangalore etc. here, major focus needs to be on mitigation of micro-climatic changes through adoption of green building norms like green rating for integrated habitat assessment (GRIHA) and leadership in energy and environmental design (LEED) certification for built-up and provision of roof garden, vertical garden, track side habitat and road side habitat to increase the vegetation cover. This will help in enhancing the 'cooling effect' due to increased evapotranspiration from the vegetation cover and thus, facilitate the mitigation process of micro-climatic changes in the metropolitan cities.

References

Chebet, C. (2013). An Assessment of Land Use and Land Cover in and Around Kakamega Forest in Kanya Using GIS and Remote Sensing.*Journal of Emerging Trends in Engineering and Applied Sciences,* 4(1), 46-53.

Meyer, W.B. and Turner, B.L., (eds.) (1994). *Changes in Land Use and Land Cover: A Global Perspective*. Cambridge University Press, Cambridge, London, UK.

Lambin, E.F., Turner, B.L., Geist, H., et.al. (2001). The Causes of Land Use and Land Cover Change: Moving Beyond the Myths. *Globe Environmental Change*, 11(4),261-269.

XuChao, Yang (2009). Sensitivity of Surface Air Temperature Change to Land Use/Cover Types in China.*Earth Sciences*, 52 (8), 1207-1215.

Rhee, Jinyoung et.al. (2014). Relationship Between Land Cover Patterns and Surface Temperature in Urban Areas.*GIS Science and Remote Sensing*, 51(5), 521-536.

Qian, Cheng (2014). Impact of Land Use/Land Cover Change on Changes in Surface Solar Radiation in Eastern China Since the Reform and Opening Up.*Theoretical and Applied Climatology*, 123 (1&2), 131-139.

Liu, Fegshan et.al (2014). Effects of Land Use/Cover Change on Land Surface Energy Partitioning and Climate in Northeast China.*Theoretical and Applied Climatology*, 123 (1&2), 141-150.

Shen, Guangrong et.al.(2015). Spatio-Temporal Land Use/Land Cover Dynamics and Their Impacts on Surface Temperature in Chongming Island of Shanghai, China.*International Journal of Remote Sensing*, 36 (15), 4037-4053.

Lambin, E.F. and Ehrlich, D. (1996).The Surface Temperature-Vegetation Index Space for Land Cover and Land Cover Change Analysis.*International Journal of Remote Sensing*, 17 (3), 463-487.

Yue, W. et.al. (2007). The Relationship Between Land Surface Temperature and NDVI with Remote Sensing: Application to Shanghai Landsat 7 ETM+ Data.*International Journal of Remote Sensing*, 28 (15), 3205-3226.

Zhang, Youshui et.al.(2015). Characterizing Fractional Vegetation Cover and Land Surface Temperature on Sub-Pixel Fractional Impervious Surfaces from Landsat TM/ETM+. *International Journal of Remote Sensing,* 36 (16), 4213-4232.