Chapter 5
Spatial Correlations of Changing Land Use, Surface Temperature (UHI) and NDVI in Delhi Using Landsat Satellite Images

R.B. Singh and Aakriti Grover

Abstract Urbanization has brought major changes on the land use/cover pattern, urban heat balance and environmental status of cities across the world. Hence, spatial relationships of changing land use/cover, surface temperature and NDVI were studied using Landsat 5 TM satellite data. Study reveals that built up and green spaces have increased in the city of Delhi on the cost of adjoining agricultural and marshy lands. The surface temperature has also increased for the all the land use/cover categories during the study period (2000–2010). The NDVI has increased for central Delhi, indicating improvement in forest and tree cover. The fringe, however, reveals the negative changes in NDVI values. The surface temperature and NDVI correlation does not show strong correlation. The NDVI does not explain the surface temperature conditions properly. In view of improvement of vegetation, the surface temperature was expected to decrease; instead it has increased irrespective of land use/cover. The highest temperature was found in agricultural land unlike other urban areas where urban areas show high temperature. Therefore, there is weak heat island in Delhi. It may be associated with patterns of land use/cover.

Keywords Delhi • Surface temperature • Urban heat island • Urban micro-climate • Vegetation index

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5.1 Introduction

There has been an apparent change in the land use/cover of urban areas across the world. It is associated with expansion and intensification of concrete areas in the surrounding areas including the forest cover and agricultural lands etc. The concrete areas of Delhi have also experienced unprecedented horizontal and vertical growth, leading to the major modifications of previously occurring land use/cover. As per the records of Census of India (2011), Delhi with 11,297 persons/km^2, has maximum density in India. In 1901, Delhi was a small city with total population of only 0.4 million and urban population of 52.76 %, which increased to 16.75 million total and 97.50 % urban population by 2011. During this process of urban growth and development, substantial significant transformations in land use/cover of Delhi have taken place.

The process of urban growth has multiple consequences on socio-economic development and environmental conditions. The outward expansion of city consumes large areas of agricultural and forest land, pushing the fringe further. This urban sprawl is unavoidably accompanied with concretization, industrial growth, traffic congestion, air pollution, emission of volatile organic compounds etc., thereby modifying the urban heat budget and raising the temperature of the city core (Roy et al. 2011; Yang and Lo 2002; Singh et al. 2014; Lo and Quattrochi 2003). The phenomenon wherein the temperature of urban centers is higher than the rural hinterland is called Urban Heat Island (UHI). There are three types of Urban Heat islands—Surface Urban Heat Island, Canopy Layer Urban Heat Island and Boundary Layer Urban Heat Island. The latter two types of UHI belong to atmospheric heat islands. Surface heat islands are greatest in the day and atmospheric heat islands in the night (Lo and Quattrochi 2003). The land use/cover and surface temperature are positively correlated owing to albedo and moisture content of the respective surface type (Lo and Quattrochi 2003) and hence UHIs can be identified on the basis of surface temperature differences (Lo and Quattrochi 2003; Oke 1995).

The assessment of land use change as a field of enquiry is decades old but the methodologies have changed over time. The remote sensing satellite data has been extensively used in recent years (Torres-Vera et al. 2009; Muttttanon and Tripathi 2005). The land use/cover change studies using the satellite images are abundantly available. Torres-Vera et al. (2009) analyzed the urban growth for a period of three decades (1973–2000) in Mexico City utilizing the Landsat MSS, TM and ETM+ data. Muttttanon and Tripathi (2005) observed the changing pattern of coastal zone of Ban Don Bay of Thailand using Landsat 5 datasets for 1990, 1993, 1996 and 1999. The change detection analysis was carried out using supervised land use/cover classification and correlating the results with NDVI values in order to highlight the changes from vegetation to other land uses and vice versa. Li and Zhao (2003) evaluated the urban land use patterns spanning over a period of 14 years for the city of Mississauga in Ontario by utilizing the Landsat TM images of 1985 and 1999. They concluded that the drastic changes in urban land use/cover had resulted in depletion of vegetative cover that is replaced by buildings, roads, malls and other concrete structures. The results were validated using vegetation-impervious surface-soil model. Similar results were presented by Mundia and Aniya (2005) in understanding of urban expansion of Nairobi city using Landsat images, Yuan et al. (2005) for Twin Cities of Minnesota Metropolitan Area, Jiang and Tian (2010) for the capital city of Beijing, Yang and Lo (2002) for the Atlanta, Georgia metropolitan area in the United States. Suribabu et al. (2012) used IRS satellite images and CARTOSTAT-1 images to examine the process of urbanization in Tiruchirapalli City from 1989 to 2010.

Change in surface temperature with reference to land use/cover change has been performed with the help of thermal infrared satellite images of various satellites' sensors at different spatial resolutions. The thermal infrared sensors primarily used for mapping and analysis of surface temperature are Geostationary Operational Environmental Satellite (GOES), NOAA-Advanced Very High Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectro-radiometer (MODIS), Terra-Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Synthetic Aperture Radar Imager (SAR), Satellite Pour l'Observation de la Terre (SPOT) and Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) (Kant et al. 2009; Muttttanon and Tripathi 2005). While the GEOS data have 4 km resolution, AVHHR and MODIS—1 km and ASTER—90 m, the Landsat TM have 120 m and ETM+ have 60 m spatial resolution that makes it efficient in providing minute details and variations. Among the available thermal satellite data, the Landsat TM is the oldest, hence is available for longer time series (1987–2011). Research on changes and impact of urbanization in altering thermal balance has been conducted all over the world e.g. Lo and Quattrochi (2003) on Atlanta Metropolitan Area, Li et al. (2011) on Shanghai and Bagan and Yamagata (2012) for Tokyo, Zhang and Wang (2008) in different parts of China and Chen et al. (2006) on Pearl river delta. The magnitude and extent of UHIs have been found to be positively correlated with the size of cities, level of urbanisation and population size, indicating the significant impact of urban growth on creation of micro-climates (Hung et al. 2006).

NDVI values range between +1 and -1 and higher NDVI indicates a higher degree of greenness and healthy vegetation (Lo and Quattrochi 2003; Curran 1980). Since surface temperature and NDVI exhibit inverse relationship, it acts as a chief indicator of land use/cover change. The works on UHI and NDVI are immense e.g. Zhang et al. (2012) presented the case study on Wuhan City, Weng et al. (2004) on Indianapolis, Zhang et al. (2010) on Beijing, Julien et al. (2011) on Iberian Peninsula, Yue et al. (2007) on Shanghai, Amiri et al. (2009) on Tabriz urban area, Iran and Kawashima (1994) on Tokyo. However, in context of Delhi, literature on the related theme is sparse. Pandey et al. (2009) examined daytime and night-time thermal data in association with distribution of Aerosol Optical Depth observing that areas with high AOD levels and low temperature and vice versa. Rahman et al. (2011), Mohan et al. (2011), Sharma and Joshi (2012) and Mohan et al. (2013) have used satellite based platforms to analyze land use/cover and associated temperature changes in Delhi.

Due to modification of urban land use/cover and associate changes in area covered by vegetation, water bodies and built-up areas cause the surface temperature to increase. With higher percentage of population now living in the cities, these alterations are much more evident there. UHI is responsible for increased heat events and mortality related to heat wave. The higher temperatures bought by urban heat island also has adverse effect on the air quality. According to Lo and Quattrochi (2003) volatile organic compounds and nitrogen oxides, emitted from industries, power plants, vehicles and combustion of fossil fuels, in presence of sunlight react to form ground level ozone (Cardelino and Chameides 1990). The ground level ozone is a public health hazard that causes various respiratory and cardiovascular problems. Increased pollution levels strongly associated with amendments in surroundings and urban lifestyles is the prime cause of degrading heath in urban areas. Respiratory illness, skin and eye infections are on a rise. Considering the negative impacts of the changes in land use/cover, this paper focuses on (1) Status of changing land use/cover in the capital of India, Delhi from 2000 to 2010, (2) to understand the pattern of changing surface temperature 2000–2010 and (3) to understand the relationship between changing land use/cover and surface temperature using NDVI for the same period.

5.2 Study Area

Delhi is the administrative and national capital of India. It is located between the latitudinal extent of 28°23′17″–28°53′00″ N and longitudinal extent of 76°50′24″–77°20′37″ E (Fig. 5.1) and covers an area of 1,483 km^2 with average altitude of 213–305 m above msl. It is bordered by Haryana in the north, west and south and Uttar Pradesh in the east. Delhi has two main physiographic features viz. the Yamuna river and Delhi ridge. Apart from this, the city is largely a plain area. The length and average width of river Yamuna in Delhi are 48 km and 1.5–3 km respectively. It divides the city in two parts, popularly known as east and west Delhi. The ridge, which is an extension of Aravalli Range, borders the Delhi in southern side and extends upto central Delhi. It is popularly known as Lungs of Delhi, as it functions like thermal moderator and cooling agent of climate. Delhi has extreme continental climate with annual temperature ranges from 3 °C in winters to 45 °C in June and average rainfall ranges from 400 to 600 mm.

For the purpose of governance and management, Delhi city is divided into nine districts and 27 tehsils/sub-divisions. Unlike many large growing cities of the Asia, Delhi posses mixed land use/cover comprising of built up area interspersed by layers of tree cover. As per the estimates of the Forest Survey of India the total forests cover in Delhi was about 22 km^2 (1.5 %), which increased to about 176.2 km^2 (11.88 %) in 2011. Besides, lush green tree cover has grown that cover about 120 km^2 (8.09 %). The vegetation on the ridge mainly belongs to thorny scrub type, representing semi-arid conditions.

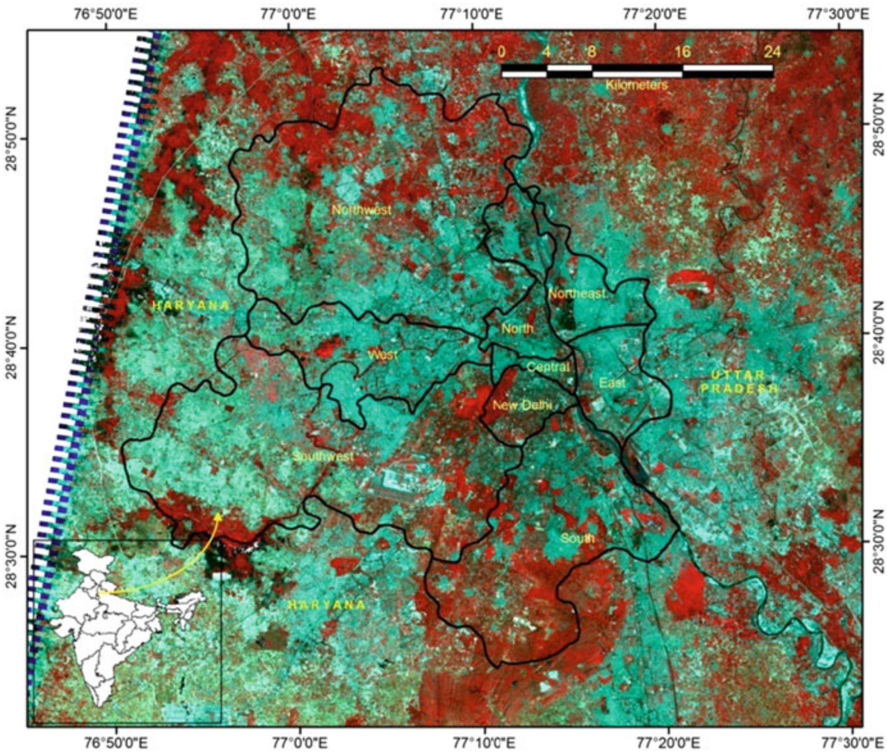

Fig. 5.1 Location of study area i.e. Delhi in India. Background: Landsat 5 TM standard FCC (4, 3 and 2)

5.3 Database and Methods

To understand the changes in micro-climate viz. land use/cover, NDVI and surface temperature of Delhi, Landsat 5TM satellite images were acquired from www.earthexplorer.usgs.gov (Table 5.1). The Landsat 5 satellite following a Sun-synchronous, near-polar path revolves around the earth at an altitude of 705 km with 16 days temporal resolution. It overpasses the Delhi at local time of approximately 10:30 am. The data is obtained in seven spectral bands. The 6th band is thermal infrared band and is mainly used for mapping of surface temperature. The other bands are used for land use/cover information with different combinations of bands usually known as false color composites (FCC). The spatial resolution of the 6th band is 120 m, while the other bands are obtained at 30 m resolution (Chander et al. 2009; Murayama and Lwin 2010).

Table 5.1 Satellite data used in present study

Satellite	Sensor	Acquisition date	Path and row	Spatial resolution[a]
Landsat 5	TM	5/5/2000	146/040	30 m
Landsat 5	TM	9/5/2010	146/040	30 m

[a]120 m for thermal data (6th band)

5.3.1 *Image Pre-Processing*

The satellite images were raw in nature and radiometric corrections were to be applied to make them usable for further research. After identifying the area of study (Fig. 5.1), the image (all bands except 6^{th}) was converted to reflectance image for further analysis. Following image pre-processing steps were taken to convert raw image to reflectance image based on Chander et al. (2009).

Step 1. Conversion of the Digital Number (DN) to Spectral Radiance (L)

$$L_\lambda = LMIN + (LMAX - LMIN) * DN/255 \qquad (5.1)$$

where: L_λ is the Spectral radiance, LMIN is the 1.238, LMAX is the 15.600 and DN is the Digital Number

Step 2. Conversion of Spectral Radiance to Reflectance

$$\rho\lambda = \pi d^2 L_\lambda / E_{0\lambda} \cos\theta_s \qquad (5.2)$$

where: ρ_λ is the Reflectance, d is the Earth-sun distance (astronomical units), L_λ is the Radiance, $E0_\lambda$ is the Mean solar exoatmospheric irradiance, π is the 3.14159, θ_s is the Angle of solar zenith(degrees).

5.3.2 *Land Use/Cover Classification, Mapping and Change Detection*

Delhi is an amalgamation of multiple land use/cover types and hence broadly six categories were identified including, built-up land, vegetation-green space, water bodies, agricultural area, bareland and sand bars on the satellite images of 2000 and 2010 using Erdas Imagine 9.2. Supervised classification method was applied for mapping of land use/cover classes. Over 25 signatures from each land use/cover type were acquired with the help of field based knowledge, current topographical sheet and google earth. These were further cross-checked at field, hence the maps were prepared. Both the maps were further compared to understand the land use/cover change.

5.3.3 Mapping of Surface Temperature: Pre-processing, Conversion and Change Analysis

The raw thermal band (6th band) was converted to spectral radiance (L) using Eq. (5.1). The spectral radiance was then converted to temperature in Kelvin (using Eq. (5.3)) and thereafter in degree Celsius scale (using Eq. (5.4)) following Chander et al. (2009), Murayama and Lwin (2010) and Jiang and Tian (2010).

Step 1. Conversion of the Digital Number (DN) to Spectral Radiance (L) using Eq. (5.1)

Step 2. Conversion of Spectral Radiance to Temperature in Kelvin

$$T_B = K2/\mathrm{In}((K1/L_\lambda) + 1) \tag{5.3}$$

where: K1 is the Calibration Constant 1 (607.76), K2 is the Calibration Constant 2 (1260.56),

T_B is the Surface Temperature

Step 3. Conversion of Kelvin to Celsius

$$T_B = T_B - 273 \tag{5.4}$$

The north–south and west–east surface temperature profiles were calculated for both the years i.e. 2000 and 2010. The profiles were created in such a way that they cross the central Delhi and cover most land use/cover types. One thousand four hundred thirty four sample pixels for north–south profile and 1,271 sample pixels for west–east profile from thermal image of each year were taken into consideration. The profiles were further compared using simple line graph.

5.3.4 NDVI Estimation and Change

The NDVIs of processed satellite image were calculated using Eq. (5.5).

$$\mathrm{NDVI} = (\mathrm{band4} - \mathrm{band3})/(\mathrm{band4} + \mathrm{band3}) \tag{5.5}$$

Further, NDVI change was computed and relationships between land use/cover and surface temperature and NDVI established. The profiling of NDVI for the same sample pixels was done using line graphs as for the surface temperature.

The profiles of NDVI and surface temperature representing land use/cover classes for both the years were then compared using line graphs. The comparison has also been done using the maps of land use/cover, surface temperature and NDVI (Fig. 5.2).

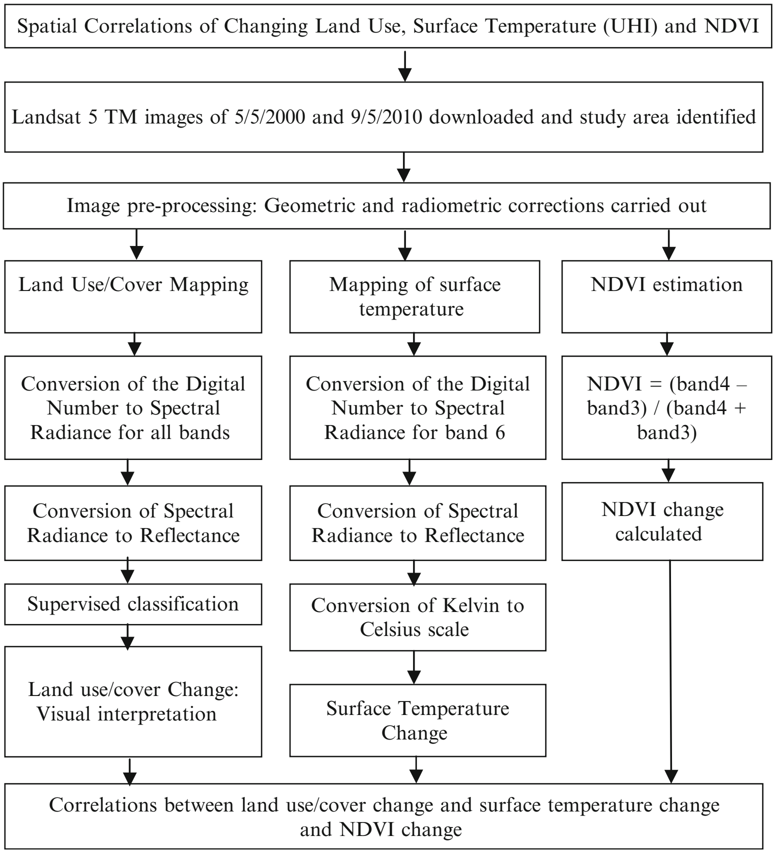

Fig. 5.2 Methodological framework

5.4 Results and Discussion

The visual correlations between land use and cover and surface temperature of 2000 and 2010 show that there is strong positive relationship among the two. As the surface characteristics change the temperature also alters (Fig. 5.3). The forested areas and vegetation cover have minimum surface temperatures. This is for the reason that vegetation absorbs incoming solar radiation, thereby reduces the heat. Water bodies like presence of river Yamuna and lakes like Bhalaswa, Sanjay Gandhi Lake moderate the temperature around it. This is due to differential heating of water bodies, difference in albedo and high absorption power of water. On the other hand, higher temperatures are associated with non-porous materials like building, roads made of concrete, asphalt and metal (Yue et al. 2007; Lo et al. 1997).

The surface temperature for south west part of Delhi is maximum owing to the presence of fallow land and sandy soil. As perceived, in central part of Delhi and in areas of high built up density, the temperatures are not very high. Unlike many other

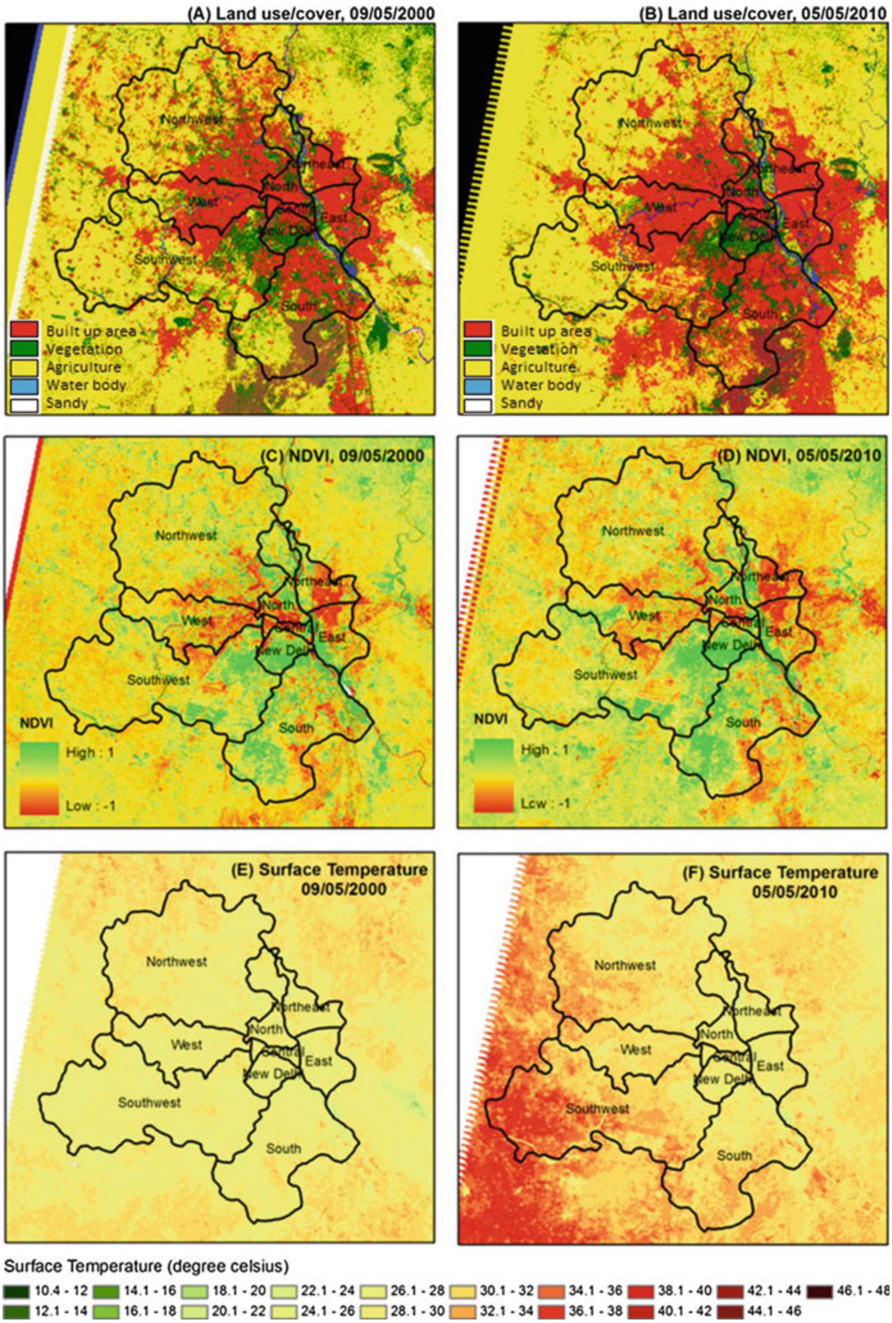

Fig. 5.3 Spatial distribution of land use/cover, surface temperature and NDVI in Delhi (2000 and 2010)

large cities of the world, like Tokyo, Shanghai, Georgia, Beijing and many Asian cities, this pattern is an atypical phenomenon. Delhi is exceptionally unique as over the past few years, along with accelerated concretization, there has also been expansion in tree cover of Delhi leading to creation of mixed land uses. Most of the highly compact built up areas are accompanied with dense tree cover, thereby, fostering a balance in the surface temperature. Added to this is the minimizing role of the Yamuna River that crosses through seven of total nine districts of Delhi. Another possible factor is the building size. Delhi city has grown more horizontally in comparison to vertical growth and therefore the occurrence of heat trap is minimal. As a result very strong heat island does not exist in the centre of Delhi, but, it may be noted that there is clear distinction and variation in thermal properties according to the land use/cover type.

To further investigate on association between land use/cover and surface temperature, NDVI was calculated (Fig. 5.3). There exists inverse relationship between NDVI and surface temperature. In 2010, sections of South Delhi, New Delhi and North Delhi have experienced an increase in NDVI values in comparison to May 2000. Increase in green cover is striking in the districts of South and New Delhi. On the other hand, the values decreased in North–East, East and North–west Delhi. It is clearly visible that the geographical city of Delhi has expanded last census decade. As per the results of NDVI, higher temperatures should be in North–East, East and North–west Delhi but such is not the case, for the reason that greenness in the city has been maintained judiciously along with horizontal expansion of the city. The presence of river Yamuna in these districts has also contributed in lowering the temperature. The surface temperate pattern depicts a varied scenario. The city temperature was much lower for the hottest month of the year in 2000 and 10 years later the surface temperature for the same month increased significantly for all districts.

As per the records of Survey of Forest in Delhi, 2001, total forest cover in Delhi was 111 km^2, that is, 7.6 % of the total geographical area of Delhi. This comprised of 38 km^2 dense forest cover and open forest of 73 km^2. New Delhi (27.88 %) had maximum forest cover followed by South Delhi (21.02 %) and Central Delhi with 9.20 % in 2001. All other districts had less than 5 % forest cover. However, in 2011 Report of Forest Survey of India, the total forest land increased to 176.2 km^2 which is a rise of 4.32 % in a decade. South Delhi recorded maximum forest cover with 78.32 % followed by South-West Delhi with 41.8 % and minimum of 4.1 and 2.99 % for North-east and East Delhi.

The decadal change in surface temperature (degree Celsius) and NDVI are represented in Fig. 5.4. The change in surface temperature ranges from −6 to 10 °C, an enormous difference of 14 °C. Apart from the border areas of west, south west and south central areas, the change ranges between 0 and 2 °C except a few pockets. The maximum change has taken place in South–west district. NDVI has increased in North, Central, South and New Delhi. The east, north and western Delhi are the areas where the city expansion has taken pace and hence the NDVI values are lesser there.

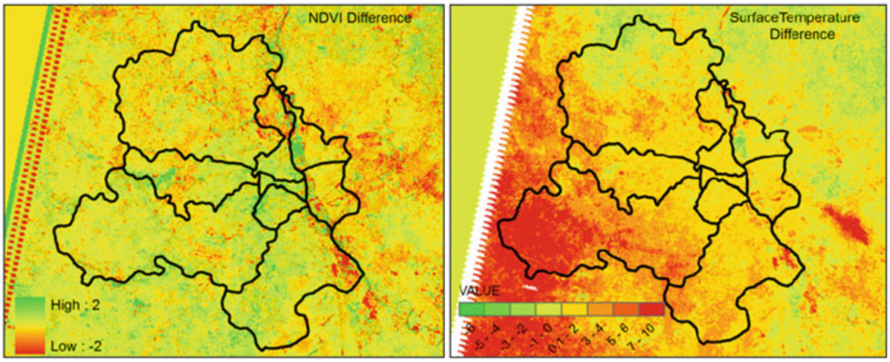

Fig. 5.4 Changes in NDVI and surface temperature in Delhi (2000 and 2010)

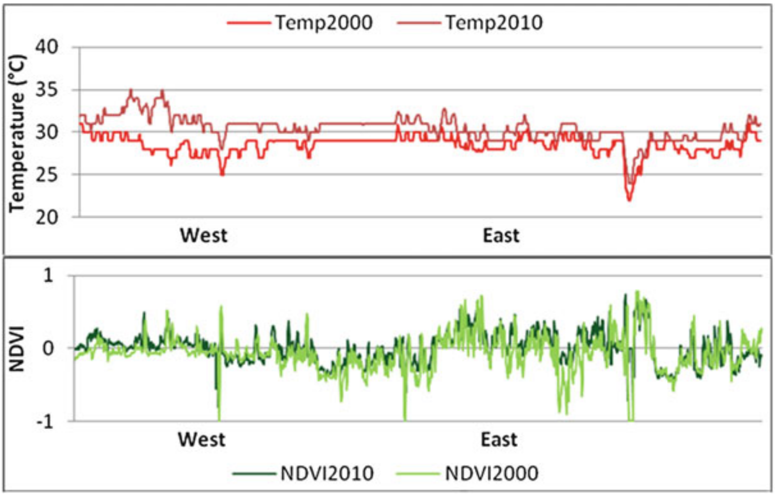

Fig. 5.5 West–east profile of temperature and NDVI

The north–south and west–east profile lines were drawn cutting across Delhi and land surface temperature and NDVI values correlated along the profile lines (Figs. 5.5 and 5.6).

The west–east profile shows that overall the temperature has increased in Delhi. In 2010, the temperature gradually decreases from west to east and the Central Delhi experiences 27–32 °C temperature. It reaches a maximum of 35 °C in West Delhi and minimum of 24 °C in east at the river Yamuna. Most of the east Delhi areas have maximum temperature of 30 °C except the border areas. In 2000, temperature was much lower in the western portion. The average temperature of river Yamuna has also increased. NDVI results of west–east profile is highest in East Delhi, moderate in West Delhi and least in Central Delhi that is in contrast to temperature pattern. These results are attributed to low height of building and the existence of perennial river Yamuna that flows across the city.

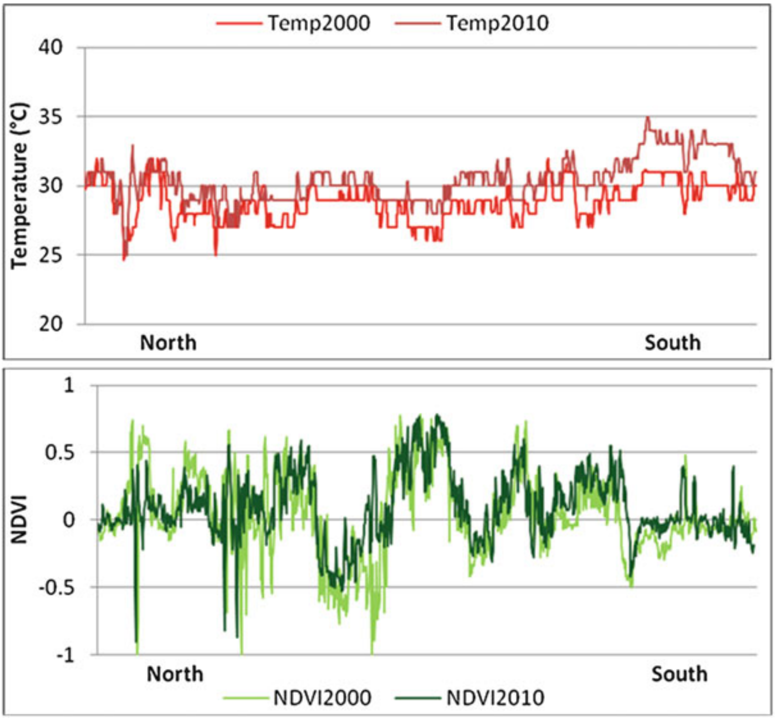

Fig. 5.6 North–south profile of surface temperature and NDVI

The north–south profile lines pass through the districts of North Delhi, Central Delhi, New Delhi and South Delhi. The temperature increases as we move towards the extreme South and in Central and New Delhi it is low (Fig. 5.6). The thermal conditions have observed an increase from 2000 to 2010, and the NDVI also experienced gain at many places. The NDVI is largest in New Delhi despite large congregation of buildings. In extreme north and south, however, the NDVI values are much lower. There is clear correlation between surface temperature graph and NDVI values as areas having higher vegetation index have comparatively low temperature conditions and vice versa. The high level of greenness in the capital city is accountable for maintaining relatively low temperature and the absence of clear urban heat island even during the hottest month of the year in May.

5.5 Conclusion

Delhi has physically grown phenomenally in recent past. Ever increasing population and urban growth has led to many changes in its environmental conditions. Unlike other Asian cities, it has unique land use/cover distribution. It has large area under forests and tree cover and that too in central part of city, which is unusual for any city. The ridge covered with forests penetrates in the central parts from the southern sides acting as the moderator of its climate. The agricultural areas are distributed well outside the cities, however large tract were noticed along the river Yamuna that divides the city in two parts. The presence of agricultural land in middle of city is also rarely seen in many cities of the world. All of these phenomena moderate the heat intensity of the central part of city. The surface temperature is well correlated with land use/cover categories. The highest temperature is not observed in built-up land, as there are healthy forests, tree and green cover within the built-up land. It mitigates the heat intensity and albedo. Presence of perennial river in middle of the city also has mitigating influence. The NDVI does not properly explain the distribution of temperature in Delhi, suggesting there are other un-understood factors. The temperature has however increased for all the land use/cover categories. The study concludes that there is absence of prominently large scale heat island in Delhi, rather there exist small scale heat islands spread across the city.

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