Urban Heat Island: Introduction to Mitigation

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Abstract: ***As population is increasing significantly and our economies become more industrialized, as may result more person have shifted from rural to urban areas. Urbanization is increasing as the people are attracted towards the job opportunities and facilities provided in urban areas. One of the major effect of the urbanization and industrialization is the people living in urban areas, means decrease in vegetation and increase in concrete hard land. "Urban Heat Island" is an urban area having impermeable and concrete land which is warmer than the surrounding area covered by vegetation and green spaces. Permeable surfaces are replaced by impermeable surfaces and materials which are used in buildings and pavement are hard and are non-reflective which absorbs heat and emit later which upsurges the temperature of surrounding and creates microclimate. Use of no reflective surface materials, low albedo materials, hard pavements, less trees and vegetation can cause Urban Heat Island and could increase the intensity of UHI. Planting trees, use of albedo materials and high reflective materials can help in declining the impact of UHI in urban areas. Some planning interventions like, availability of green spaces, height of buildings and width of roads could also help in reducing the intensity of UHI.***

Keywords: Urbanization, Urban Heat Island

1.Introduction

From last few years, urbanization is increasing in urban areas, causing increase in urban infrastructure and number of vehicles. Permeable surfaces that are substituted with impermeable and concrete surfaces with tall buildings in cities. Impermeable and concrete surfaces be likely to trap heat and sun radiation at day time and emit it later which results in increasing the temperature of that particular urban areas and observing that high temperature. It is projected that for every 0.6° C increment in surrounding temperature, electricity consumption began increasing at the rate of 2%. (Enviromental Management and Policy Research Institute (EMPRI), 2017).

The purpose of the paper is to assess the intensity of urban heat island in different areas and to identify mitigation strategies to curtail the influence of "Urban Heat Island".

An urban approach to environment sensitive design as UHI is an arena of stationary warm air over the densely built-up areas of the urban area. Higher temperature likely to be experienced in urban and suburban areas than their surrounding rural areas. This temperature difference can be as high as 1°C to 3°C for a 1million populated city, while it could be higher up to 12°C on a clear sunny summer day. (Environmental Management and Policy Research Institute (EMPRI), 2017). World Bank says that UHI can be recognized as an urban area having its own microclimate and warmer than the surrounding areas. These urban areas have a tendency to trap warm air during the sunny day which can be originated by both solar radiation absorption and human activity. The absorbed heat than released at night and this night-time air temperature in urban areas becomes higher than surrounding rural areas. This temperature difference in urban and rural areas is known as "Urban Heat Island". Numerous buildings are intended to take account of this phenomenon for the purpose of keeping their interior temperature within definite limits. (Agenda, n. d.)

One could understand about Urban Heat Island by understanding two different types.

Surface UHI - When solar radiation and heat is trapped by the impermeable and dry surfaces. S'UHI defines the intensity of solar radiation and is higher at day time when intensity of sun is higher. That's why Surface UHIs are highest during summers and specifically during day-time.

Atmospheric UHI - Difference of temperature between urban and rural surroundings.

Canopy layer UHI - It exists from ground surface to the uppermost layer of buildings and trees. Boundary layer UHI - It exists from the uppermost layer of trees and buildings to the atmospheric layer where the urban landscape doesn't influence the atmosphere.

Causes of Urban heat island

a. **Use of low albedo materials**-Low albedo materials are the materials which reflects less radiation and absorbs most of the energy. Therefore, temperature over the low albedo material is higher than over the high albedo material.
b. **Permeable surfaces replaced by impermeable surfaces** - Permeable surfaces allow water penetrate into ground and maintain the surface temperature. Where, impermeable surfaces don't allow absorbing water and letting it run-off.
c. **Use of heat absorbent and dark coloured materials** - Dark coloured materials tend to heat up more than light coloured materials as they are good heat absorbent than light colour. Dark materials absorb heat and make an area warmer than area with light coloured materials.
d. **Lack of evapotranspiration** - Evapotranspiration is the process includes evaporation and plant transpiration at same time. Water present in trees and plants makes the environment cool, affects the solar radiation also.
e. **Increase in no. of vehicles** - Vehicles emits carbon dioxide and greenhouse gases in environment and creates pollution. Increasing pollution creates warmer temperature in the environment with more population

and more no. of vehicles.

f. **Urban canopy** - tall buildings forms urban canopy which traps solar radiations and emits later which creates warm temperature in that area and creates a micro climate.

Impacts of UHI

Increase in temperature due to heat island can affect the communal environment and quality of life in many ways:

a. **Increased energy consumption**-increase heat island would increases the demand in energy consumption for cooling appliances to cool buildings. Increased energy costs are also a result of rising demand. Heat islands cause temperatures to rise, resulting in increased power demand and overall energy demand. Peak demand occurs in the afternoons of hot summer days, when air conditioners and other equipment are used in offices and homes.
b. **Raised emission of harmful, polluted and greenhouse gases**-summer energy demand rises as an outcome of heat island effect. Enterprises that provide electricity mostly be dependent on fossil fuels power plant to encounter their needs, resulting in increased air pollution and greenhouse gas emissions. If all other factors remain constant, such as increased gas releases in the air, wind speed and direction, hence more ground level ozone is created as a result of toxic gases (nitrogen oxides, volatile organic compounds, smog, and so on), making the environment brighter and hotter.
c. **Jeopardized human health and comfort**-heat islands rise the temperature throughout the day and lower the temperature at night, results in heat related deaths and disorders such as malaise, non-fatal heat stroke and respiratory problems. Extreme heat events and rising temperature are dangerous and can effect average mortality. In these incidents sensitive people such as children, the elderly, and people who already suffer from health problems face greater risks.
d. **Damaged water quality-**High temperatures of earth's surfaces, sidewalks and roofs can warm storm water runoff in storm sewers and raise the temperature of water as it is distributed in streams, waterways, lakes etc. high temperature of water would affects all aspects of aquatic life, predominantly the digestive system and the production of aquatic species.
e. **Impacts on weather and climate**-Other than high temperature, UHI can deliver auxiliary impacts on nearby climate and environment. This evokes changes for nearby wind designs, the arrangement of haze and mists, precipitation rates and dampness. The uncommon warmth brought about by UHI adds to a more exceptional vertical breeze development that can invigorate thunderstorm and precipitation movement.

Evolution / origin of problem

Urban heat island is the repercussions of increasing urbanization and development which leads to changing radiation and thermal properties of urban infrastructures. When the materials used in surfaces of buildings and earth is non-reflective, thermal absorbent and non-porous i.e. impervious layers are widely used in an urban area. These materials absorb heat at daytime and emit it later which creates and heat island around that urban area.

Study Area

Delhi being a modern city and the capital city of India, with arrangement of different land-use/ cover, atmospheric imbalances hence it is chosen as study area. It is physically located on Latitude 28 23' 17" North - 28 53' 00" North and Longitude 76 50' 24" East - 77 20' 37" East and lies at a height between 213 to 305 meters. Delhi has an area of 1, 483 km² and has a population of 1.68 crores according to census 2011. It has density of 11, 320 person per km². About 97% of Delhi's population living in urban areas. It is positioned at the bank of Yamuna River. Delhi is divided into segments: The Yamuna flood plains, the ridge and the plain.

- The Yamuna flood grasslands to a certain extent low lying and sandy.
- Most overlooking physiographic topographies of this region lies in the ridge area.

It started from Aravalli hills of Rajasthan and entering from south of Delhi, stretching out north-eastern way. This area of Delhi mostly has thorny type forests.

As per Indian State of Forest Report (SFR)-2015, the total forest cover and tree cover in capital city Delhi is 299.77 km² (20.22% of the total area). It consists of 111 km² of tree cover and 188.77 km² of forest cover.

Location

(South-West, East & New Delhi areas)

Two areas of Delhi are selected for this study which are the warmest and coolest area by the comparison of Delhi land use plan and LST plan of Delhi. South west Delhi is the warmest area and parts of East, South-East and New Delhi are the areas having lower temperature in the city.

Figure 1: Location of study area

Table 1: Rural and Urban area of Delhi. Source: Census of India 1991, 2001, 2011

S.no.	Classification of area	1991		2001		2011	
		Sq. km.	%	Sq. km.	%	Sq. km.	%
1.	Rural	797.66	53.79	558.32	37.65	369.35	24.90
2.	Urban	685.34	46.21	924.68	62.35	1113.65	75.1
	Total	1483.00	100.00	1483.00	100.00	1483.00	100.00

South - West Delhi

It is situated at South West part of N. C. T of Delhi in the middle of latitude 28 40’ to 28 29’ and longitude 76 50’ to 77 14’. It has three subdivisions - Kapashera Sub-division, Dwarka Sub-division and Najafgarh Sub-division. It is surrounded by the boundaries of Gurugram, Bahadurgarh and Jhajjar of Haryana, West Delhi, Central Delhi, New Delhi, and South districts of Delhi. This district has large no. of government offices. It has a distinction of having largest settlement in Asia at Dwarka.

East Delhi

East Delhi is situated at the banks on Yamuna River and divides Delhi into two parts. It is situated in the middle of latitude 28 38’ and longitude 77 17’. It is surrounded by the border of Uttar Pradesh including of Noida and Ghaziabad. It has some of the most important administration and commercial centers. This district has a distinction of having all types of income groups by this means providing all the facilities to fulfill their needs. Due to Yamuna River, this district has alluvial soil, which is very fertile and rich in silica and aluminum.

New Delhi

New Delhi district lies at the heart of the capital city and was designed by Sir Edwin Lutyen’s in geometrical pattern over a triangular base with three major functions at its apex: commercial, governmental and recreational. It is to be found between latitude 28 61’ and longitude 77 20’. It is bounded by Yamuna River on one side and ridge on other side. It is adjacently located near the ancient city of Shahjahanabad and spread out to ring road. Main landmarks such as Rashtrapati Bhawan, Parliament House, Supreme Court, Delhi High Court and Central Government Ministries comes within the zone.

2. Analysis

- **Rural and urban population of districts of Delhi 2011.**

Table 2: Rural and urban population of districts of Delhi 2011. Source: Census of India and Primary Census Abstract 2011

S. no.	District	Population		Total	% of Urban Population
		Rural	Urban		
1.	South West	1, 43, 676	21, 49, 282	22, 92, 958	93.73
2.	East	3, 530	17, 05, 816	17, 09, 346	99.79
3.	New Delhi	----	1, 42, 004	1, 42, 004	100.00

- **District wise density and growth of Delhi 2011.**

Table 3: District wise density and growth of Delhi 2011. Source: Census of India and Primary Census Abstract 2011

S. no	District	Area (sq. km.)	Density	Decadal growth (%)	% of Delhi Population
1.	South West	421	5, 446	30.6	13.70
2.	East	64	26, 709	16.68	10.18
3.	New Delhi	35	4, 057	-20.7	0.85

- **Master plan**
- Land use distribution of Master Plan of Delhi 1962. (Gupta, 1962)

Table 4: Land use distribution of Master Plan of Delhi 1962. Source: Delhi Development Authority (Master plan Delhi 1962)

S. no.	Land and development	Area (acres)	Area (%)	Remarks
1.	Residential	30, 000	48.23	As regards provision of major roads, roads, community facilities, rehousing and redevelopment these will form a part of land development programme.
2.	Commercial	1, 900	3.05	
3.	Institutional	4, 800	7.71	
4.	Government	500	0.80	
5.	District & regional parks	25, 000	40.19	
	Total	62, 200	100	

- Land use distribution of Master Plan of Delhi 2001 & 2021. (DDA, 1990) (Authority, 2007)

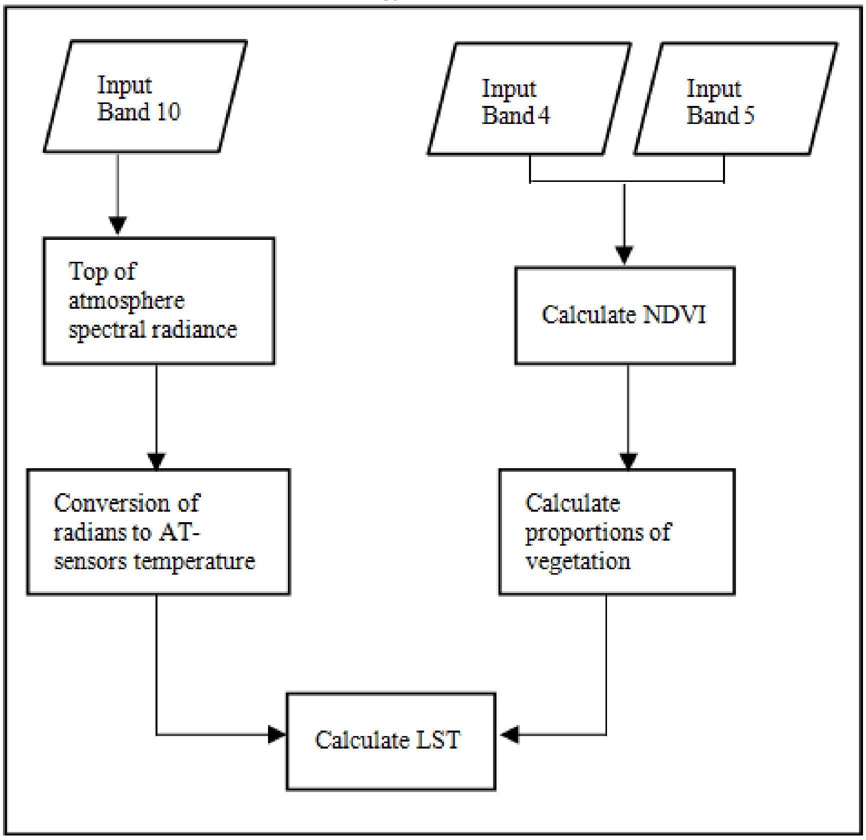
Table 5: Land use distribution of Master Plan of Delhi 2001 & 2021. Source: Delhi Development Authority (Master plan Delhi 2001 & 2021)

S. no.	Land use	2001 Area (%)	2021 Area (%)
1.	Residential	45-55	45-55
2.	Commercial	3-4	4-5
3.	Industrial	6-7	4-5
4.	Recreational	15-20	15-20
5.	Public and semi-public	8-10	8-10
6.	Circulation	10-12	10-12

3. Methods and Methodology

For finding the land surface temperature of Delhi study area, ArcGIS software is used. So for this process few factors like surface air temperature, brightness temperature and these data is obtained from LANDSAT 8 from USGS earth explorer. "Now these factors will be converted into transmittance and mean atmospheric temperature though ArcGIS. And the last parameter will be emissivity which is obtained from NDVI. The remaining values all be obtained from Metadata file of satellite image data". (Khandar & Garg, 2014).

Table 6: Methodology used for LANDSAT 8 data



Following steps are required for retrieving LST:

4. Calculations for Landsat 8

1. **Calculate TOA (top of atmosphere):** Band 10 (thermal band) from LANDSAT 8 is used to calculate surface air temperature.

"$L\lambda$= M_L*Qcal+A_L"
M_L-signifies the band-specific multiplicative rescaling factor (0.0003342) Qcal-signifies Band 10 image

A_L-signifies band-specific additive rescaling factor (0.1)

"TOA= 0.0003342* "band10"+0.1"

2. **Conversion of Radiance to AT-sensor temperature.**

Later the digital numbers (DNs) are converted to reflection. The TIRS band data should be modified into spectral radiance to brightness temperature (BT) using the thermal constants specified in metadata file.

"BT= K_2/ ln [(K_1/$L\lambda$) +1]-273.15"

K_1 & K_2 stand for band-specific thermal conversion constants from metadata file.

"BT= (1321.0789/ln ((774.8853/ "toa") +1))-273.15"

3. **Converting Brightness temperature to LST**

a. Evaluation of NDVI (normalized difference

vegetation index)

NDVI is evaluated by using Band 4 and Band 5 of Landsat 8 i.e., Red and NIR (Near Infrared) band respectively. The NDVI is used for vegetation information of an area. The formula is as follows:

“NDVI= Float (band5-band4) /Float (band5+band4)”

b. Evaluated PVI (Proportional vegetation index)

PVI is evaluated to find out the factors such as; soil background reflectance, directional, or atmospheric effects.
“PVI= square ((“ndvi”-ndvi min) / (ndvi max-ndvi min))”

Where ndvi max and ndvi min are the values of ndvi plan estimated above.

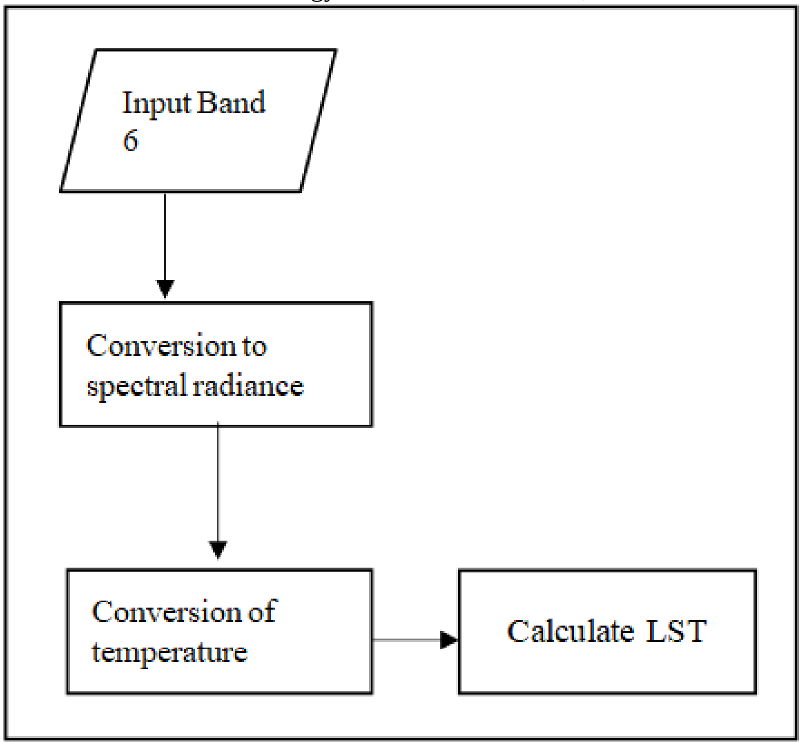
c. Calculate error corrections

“Error = 0.004* “pvi”+0.986”

d. Estimating LST (land surface temperature)

“LST= (“bt”/ (1+ (0.00115* “bt”/1.4388) *ln (“error”)))”

Table 7: Methodology used for LANDSAT 4, 5 & 7 data



Calculations for Landsat 7, 5 & 4.

a. Conversion to spectral radiance: Band 6 (thermal band) from LANDSAT 7, 5 & 4

“Lλ= (LMax λ - LMin λ) / (QCal Max - QCal Min) * (QCal - QCal Min) + LMinλ”

Here:

LMax λ: Radiance Maximum Band 6 LMin λ: Radiance Minimum Band 6 QCal Max: Quantize_Cal_Max_Band_6 QCal Min: Quantize_Cal_Min_Band_6 QCal: Band 6

b. Conversion of temperature

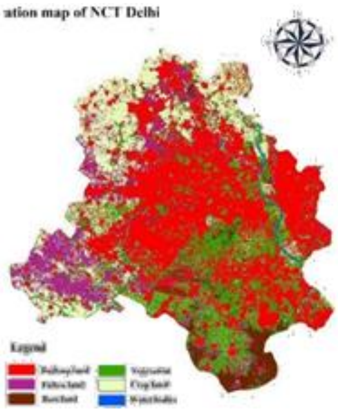
TM+ Band 6 imagery can likewise be changed over from spectral radiance (as described above) to a more physically useful variable. This is the effective at-satellite temperatures of the observed Earth-atmosphere system under an assumption of unity emissivity and using pre-launch calibration constants listed in table. The conversion formula is:

Table 8: K values of band 6 in different Landsat.

“T = (K2 / (ln (K1 / L) +1))-273.15” **Landsat**	**K1 value** (watt/ (meter squared *ster* µm)	**K2 value** (kelvin)
Landsat 7	666.09	1282.71
Landsat 4, 5	607.76	1260.56

Here:

T: Effective at-satellite temperature in Kelvin K2: Calibration constant 2
K1: Calibration constant 1
L: Spectral radiance in watts / (meter squared *ster*µm)



5.Findings

- Most of the South West area has barren land because it lies under Aravalli range.
- New Delhi district has natural features like forests, Yamuna River. Whereas South West Delhi has less amount of natural features like: green vegetation and water features.
- East Delhi has highest density however it is one of the coolest area in Delhi, on the other hand South West Delhi has way less density than East Delhi but is the warmest area in Delhi.
- South West Delhi has irregular street canopy whereas New Delhi District has planned street canopies with trees on either side of the road.
- Natural features like: vegetation, trees, water features plays a major role in creating urban heat island in any area.

6.Result & discussion

a. Land use / land cover change

Figure 3, 4 & 5 represents the land use/ land cover changes in Delhi of year 1999, 2009 and 2018. It shows that the built-up area is increasing in south-west district and East district of Delhi. Because of restrictions in New Delhi and Central area (i. e. administration buildings, foreign embassy, and governmental estate) the built-up was not expanded as much as other districts of Delhi from 2009 to 2017. However agriculture or crop land is decreasing from 1999 to 2009 and it turn out to be fallow land in 2017. (Pramanik, 2018) (Rahman et al., 2011).

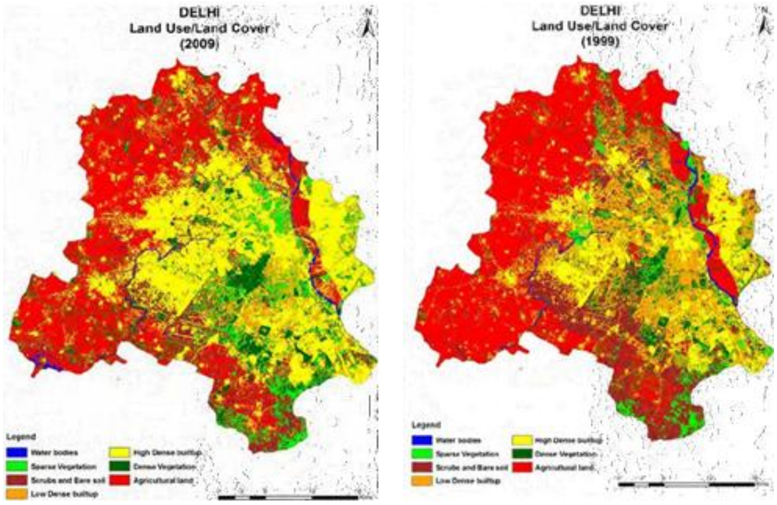


Figure 2: Land surface temperature of Delhi of year 1999, 2009 & 2018

Source: "Thermal Satellite Data for Assessment and Monitoring of surface Temperature Changes and its Impact on Micro-Climate of Delhi Addressing Grand Challenges for Global Sustainability: Monitoring, Forecasting, and Governance of Urban Systems".

Table 9: Land use/land cover changes of Delhi from 2001-2017

Land use land cover	Area (km²)		Percentage change	
	2001	2017	2001	2017
Built-up	426.26	759.74	28.74	50.22
Current fallow land	283.21	196.39	19.09	13.24
Exposed rocky bare land	116.42	75.74	7.84	5.10
Green spaces	13.83	21.23	9.42	15.51
Crop land	503.03	221.72	33.91	14.94
Water	14.37	14.3	0.96	0.96
Total area	1483.12	1483.12	100	100

Source: Diurnal land surface's thermal behaviour and socio-environmental factors: A case study in NCT-Delhi.

b.Change in vegetation - NDVI & NDBI

Figure `4 represents the NDVI map of year 2001 which describes the Normalized Difference of Vegetation Index which clearly shows the land use differences. Negative values of NDVI represents water body, lower positive values and 0 value indicates bare land and built-up areas whereas high positive values indicates high vegetation in the area. From NDVI 2001 and 2018 the vegetation is decreasing in North, North-west, and South-west districts and increase in fallow land and built-up in urban area. (Das & Das, 2017).

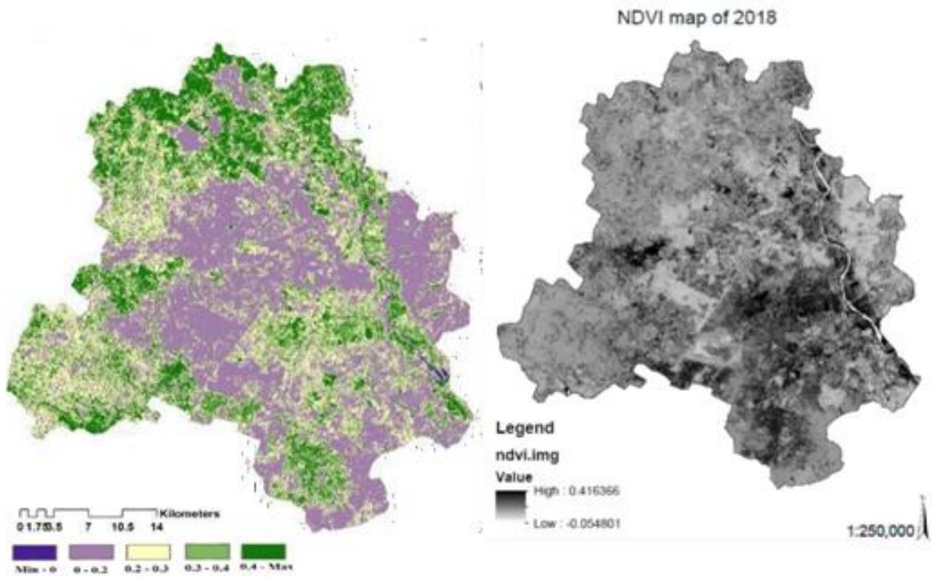


Figure 3: NDVI of Delhi of year 2001 & c 2018

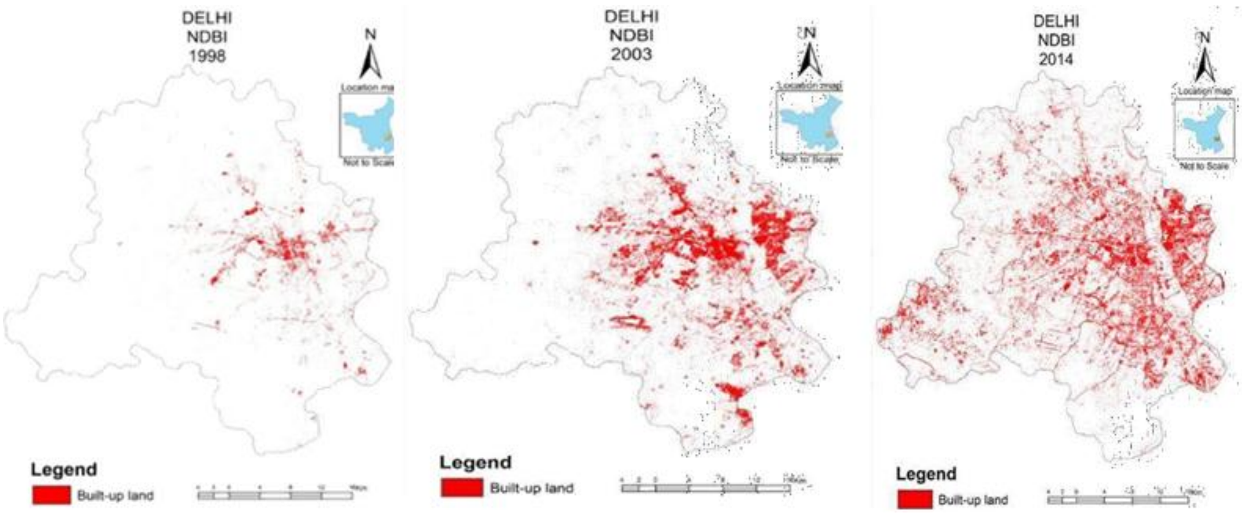


Figure 4: NDBI of Delhi 1998, 2003 and 2014. (Das & Das, 2017)

c. Relationship between LST and environment

Land surface temperature plays a major role in developing urban heat island, with the decrease in vegetation in areas and increase in built-ups, changing crop land to fallow and barren land tend to have higher temperature than the other areas and increases surface temperature which results in urban heat island.

Rapid changes in population and built-up in urban areas resulting decrease in vegetation and that impacts on the climate also which results in low precipitation and low shaded spaces which becomes hot in summer day time and releases heat at night and creates UHI.

7.Proposals and Mitigation Strategies

1.Study area specific proposals and strategies

- Pocket parks: Barren empty lands should convert into small pocket parks or areas with high built-up should include pocket parks. It has benefits such as: use of empty spaces, improve micro climate, thermal comfort, improves social acknowledgement amongst people, improve urban city environment and improves quality of life. (Athens Tackels Heat and Pollution with Pocket Parks, n. d.) (Pocket Parks, n. d.)
- Vertical gardens should mandatory for all existing and proposed development in residential and commercial areas. Trees have canopy which cools the surroundings by intercepting sunlight and transpiration. They provide

shades and absorb heat that falls on them. They can intercept up to 90% of the sunlight. That's why vertical gardens or roof gardens helps in making the building cool and makes environment cool and pollution free.

- Mitigation fees should have been applied on government for using mitigation strategies in the area. Mitigation strategies are one of the costly investments and can make financial misbalances. To overcome this crisis government or agencies should apply minimum mitigation fees on people of affected area.
- Increase Non Motor Vehicles-Limit the motor vehicles in high density local areas and encourage non-motorized vehicular movement (cycling, walking etc.).
- Evergreen trees should be planted on higher traffic volume roads.
- Trees on roadside creates buffer between people and transportation. Trees should be planted in such a way that provides better shade to the people on pathway and carriageway throughout the year.

2. Overall UHI mitigation proposals

- Street design-Neighbourhood street canopy should have maintained by grid iron street pattern for travelling wind across buildings. Wind in urban road gulley is significant for scattering heat and pollutants. Understanding wind in these gullies depends on essential standards of liquid elements. The dependency of outdoor thermal comfort on building orientation and design is important. So, instead of irregular building pattern the building should be align and let flow the wind.
- Height width ratio of building height to street width should be 1: 1-To provide better walkable streets and to prevent trapping of heat because of narrow streets and height of building, height width ratio of building to streets should be reduced from 1.5: 1 to 1: 1.
- Green roofs, vertical gardens should be mandatory for every commercial building.
- Cool materials, light colours and high reflective materials should be used in building. Roofs and pavements comprises of dark and warm materials. These materials are dark and absorb over 80% of sunlight and convert that solar energy to heat energy which results in heat island, high energy costs etc. replacing these dark materials to light and cool surfaces could adjust this warming effect and improve comfort and reduce urban heat island effects. (Ridha, 2017)
- Parking areas and local streets in residential and commercial areas should have porous pavements or pavement blocks which absorbs water and helps in maintain water table and keeps temperature cool.

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