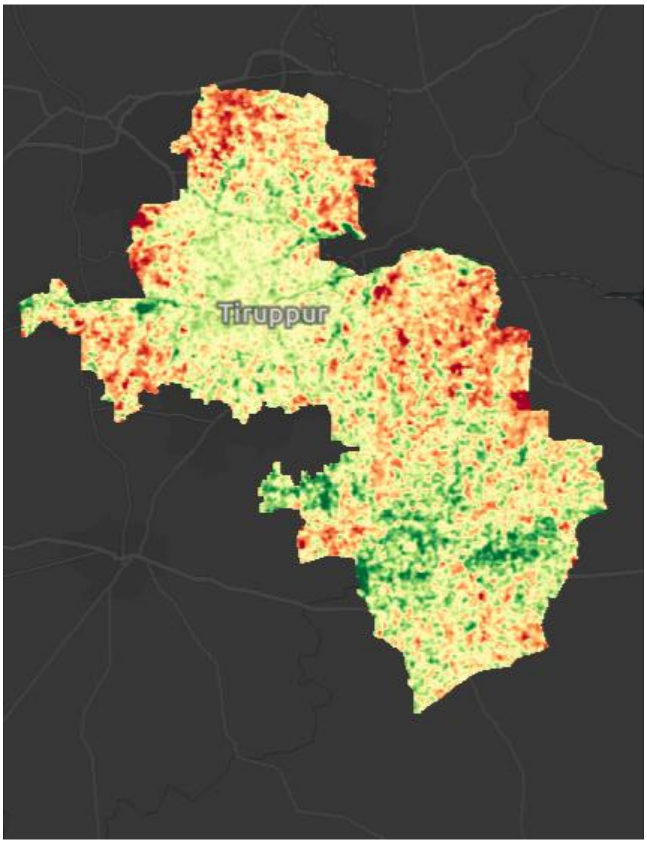



# STUDY OF VARIATION IN URBAN HEAT ISLAND EFFECT AMONG INDIAN CITIES

*By Raja Aravindh*

# CONTENTS

# ***LIST OF ABBREVATIONS***

| | | |
|---|---|---|
| *AUHI* | – | *Atmospheric Urban Heat Island.* |
| *BLUHI* | – | *Boundary Layer Urban Heat Island.* |
| *CLUHI* | – | *Canopy Layer Urban Heat Island.* |
| *LST* | – | *Land Surface Temperature.* |
| *LULC* | – | *Land Use Land Cover.* |
| *NDMI* | – | *Normalized Difference Moisture Index.* |
| *NDVI* | – | *Normalized Difference Vegetation Index.* |
| *NIR* | – | *Near Infra-Red.* |
| *OLI* | – | *Operational Land Imager.* |
| *SUHI* | – | *Surface Urban Heat Island.* |
| *SWIR* | – | *Short Wave Infra-Red.* |
| *TIRS* | – | *Thermal Infrared Sensor.* |
| *UHI* | – | *Urban Heat Island.* |
| *USGS* | – | *United States Geological Survey.* |
| *NPV* | – | *Non-Photosynthetic Vegetation.* |

# CHAPTER-1: INTRODUTION

## 1.1. General:

The purpose of this study is to analyse the urban heat island (UHI) effect in various cities across India. The term "***Urban Heat Island*** **(UHI)**" describes a micro-climatic phenomenon that occurs in urban environments. It consists of a relevant increase of the air and surface temperatures within urban areas which are thus generally warmer than the surrounding rural neighbourhoods. Usually, the temperature difference is more relevant during the night than during the day and it is most apparent when winds are weak. At seasonal level, urban heat island phenomenon occurs in winter as well as in summer (*Francesco Musco)*.

This difference in temperature between urban and rural areas is due to the changes in radiative and thermal properties of different surfaces. Natural surfaces are composed of vegetation, waterbodies and soil. These natural surfaces use relatively large proportion of the absorbed radiation in evapotranspiration process and release water vapour that contributes to cool the air their vicinity. In contrast, impervious surface such as buildings and roads are composed of no-reflective and water-resistant construction materials. As a consequence, they tend to absorb a significant proportion of incident radiation which is slowly released as heat in the form of thermal infrared radiation.

Both rural and urban systems obtain energy from the sun and subsequently losses energy back to the atmosphere and space. The spatial distribution of water, soil, vegetation and impervious surfaces is what accounts for temperature variability within cities. Urban areas where impervious areas are highly concentrated and greenery is limited becomes islands of higher temperature.

There are two types of Urban Heat Islands:

- **Surface Urban Heat Islands (SUHI)**
- **Atmospheric Urban Heat Islands (AUHI)**

## 1.2. Surface Urban Heat Islands (SUHI):

Surface Urban Heat Islands (SUHI) represents the radiative temperature difference between impervious and natural surfaces. SUHIs tends to be more intense when the sun is shining. Magnitude of SUHIs varies with seasons, but it is typically largest in the summer. SUHIs are primarily measured by remote sensing in the Thermal Infrared Region (TIR) of the Electromagnetic (EM) spectrum.

## 1.3. Atmospheric Urban Heat Islands (AUHI):

The warmer air in the urban areas compared to cooler air in the rural surroundings defines Atmospheric Urban Heat Islands (AUHI). Atmospheric heat islands vary much less in intensity than surface heat islands. Apart from the radiative heat, AUHIs get their heat from anthropogenic activities like waste heat emitted from vehicles, industries, etc. AUHIS are generally measured using in-situ sensors. AUHI can be subdivided into:

- **Canopy Layer Urban Heat Island (CLUHI):**
  - It is the layer of air from the surface to treetops or rooftops.
  - Thus, CLUHI is based on the near-surface air temperature measured below roof height (i.e., from the surface to treetops/rooftops).
  - It is measured by in situ sensors mounted on fixed meteorological stations or mobile traverses.
  - It is the most commonly observed AUHI of the two types and are often the one referred to in discussion of Urban Heat Islands.

- **Boundary Layer Urban Heat Island (BLUHI):**
  - It extends from treetops or rooftops to where the urban landscapes no longer influence the atmosphere (1.5 km).
  - Therefore, it is based on air temperature measured well above the height of buildings in the cities.
  - It is measured by tall towers, radiosondes and aircrafts.
  - BLUHI is often neglected in UHI studies since the cost of acquiring data is very high and has relatively smaller spatial and temporal coverage.

## 1.4. Urban Heat Island Diagram:

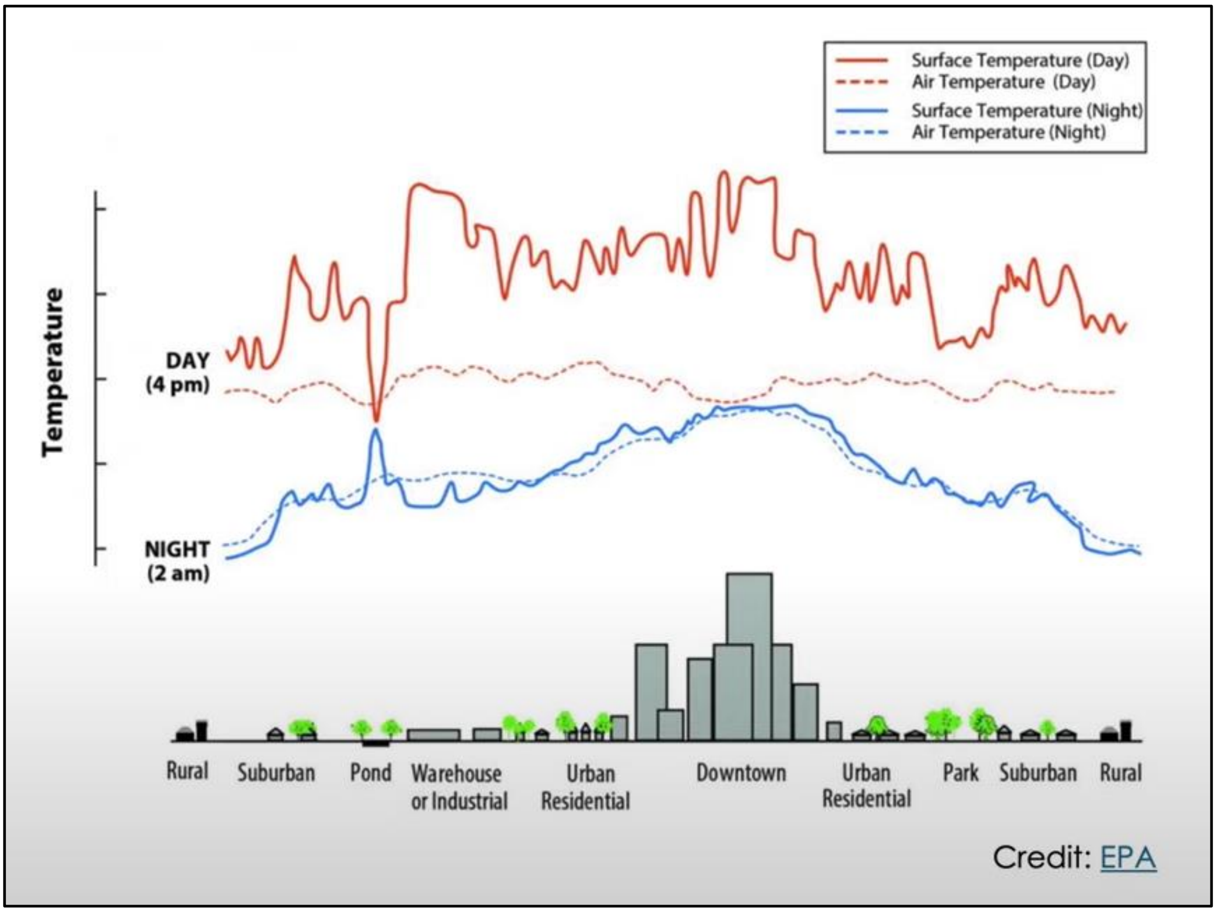



*Figure: 1.4.1: Temperature Profile.*

Figure.1.4.1 shows that surface temperatures vary more than atmospheric air temperatures during the day, but they are generally similar at night. The dips and spikes in surface temperatures over the pond area show how water maintains a nearly constant temperature day and night because it does not absorb the sun's energy the same way as buildings and paved surfaces. Parks, open land, and bodies of water can create cooler areas within a city. Temperatures are typically lower at suburban-rural borders than in downtown areas.

As we are using only the satellite images and geo-spatial techniques to study the Urban Heat Island Effect (UHI), we will concentrate exclusively on Surface Urban Heat Islands (SUHI) in our study, as the Remote sensing offers the ability to study the urban thermal environment at various spatial and temporal scales.

## 1.5. Causes of UHI:

**I. Reduced Natural Landscapes in Urban Areas**:

Trees, vegetation, and water bodies tend to cool the air by providing shade, transpiring water from plant leaves, and evaporating surface water, respectively. Hard, dry surfaces in urban areas – such as roofs, sidewalks, roads, buildings, and parking lots – provide less shade and moisture than natural landscapes and therefore contribute to higher temperatures.

**II. Urban Geometry**:

The dimensions and spacing of buildings within a city influence wind flow and urban materials' ability to absorb and release solar energy. In heavily developed areas, surfaces and structures obstructed by neighbouring buildings become large thermal masses that cannot release their heat readily. Cities with many narrow streets and tall buildings become urban canyons, which can block natural wind flow that would bring cooling effects.

**III. Heat Generated from Human Activities**:

Vehicles, air-conditioning units, buildings, and industrial facilities all emit heat into the urban environment. These sources of human-generated or anthropogenic, waste heat can contribute to heat island effects. Anthropogenic heat varies throughout the cities but can significantly contribute to heat island formation.

**IV. Weather**:

Calm and clear weather conditions result in more severe heat islands by maximizing the amount of solar energy reaching urban surfaces and minimizing the amount of heat that can be carried away. Conversely, strong winds and cloud cover suppress heat island formation.

**V. Geography:**

Geographic features can also impact the heat island effect. For example, large bodies of water can moderate temperature while nearby mountains can block wind from reaching a city, or create wind patterns that pass through a city.

VI. **Urban Material Properties**:

Material properties such as Albedo, Thermal emissivity and Heat capacity influence UHI development as they determine how the sun's energy in is reflected, emitted and absorbed respectively.

- **Albedo:**

  It is the percentage of solar energy reflected by a surface. It is inversely proportional to UHI. Urban materials absorb sun's heat rather than reflecting it, causing temperature to rise.

- **Thermal Emissivity:**

  It is a measure of a surface's ability to shed heat. It is inversely proportional to UHI.

- **Heat Capacity:**

  Heat capacity refers to surface's ability to store heat. It is directly proportional to UHI.

# 1.6. <u>Effects of UHI:</u>

- Increased daytime surface temperature and reduced night cooling and higher air pollution levels associated with urban heat islands can affect human health by contributing to general discomfort, respiratory difficulties, heat cramps and exhaustion, non-fatal heat strokes and heat related mortality.
- Children, older adults, and those with existing health conditions are particularly at risk.
- Increased energy demand for cooling and add pressure to the electricity grid during peak periods of demand can overload system. It also leads increased burning of coal, as coal is primary source for generating electricity in summer.
- Surface urban heat islands degrade water quality, mainly by thermal pollution. This increased water temperature affects aquatic life, especially the metabolism and reproduction of many aquatic species.

# CHAPTER-2: SCOPE AND OBJECTIVES

## 2.1. SCOPE:

The scope of the study is to understand the thermal dynamics between urban and rural areas and how they would interact with one another when the variation arises between them. The study will help us to understand spectral properties and thermal behaviours of different landcover types such as Barren land, Built-ups, vegetation and water bodies. It also helps us to understand how the cities in different climatic regions are influenced by the sun's radiation with respect to their rural counterparts. The study also tells us how the different vegetation types react differently to the sun's radiation.

## 2.2. OBJECTIVES:

- To identify the factors determining the formation of urban heat island among different cities across India.
- To prepare the thematic maps of LULC, NDVI, NDMI and LST for the study areas.
- To study the relationship between thermal properties of different land cover types.
- To analyse association between LULC, NDVI, NDMI and LST of the study areas.
- To analyse the variation in urban heat island effect among different Indian cities.
- To understand how different indices like NDVI and NDMI are affected by the variation in vegetation types.
- To study how the climate and vegetation type of the study area are influencing the formation of Urban Heat Island (UHI).

# CHAPTER-3: STUDY AREA

## 4.1. General:

In this study four urban conglomerates in four different states of India have been chosen. However, there is no standardized definition of "urban" and "rural" across the SUHI studies (Giridharan & Emmanuel, 2018; Weng, 2009) to date. In India, the urban built-up areas often extend beyond the administrative boundaries of city and sometimes district. To address this issue, study areas have been chosen as Taluk boundaries (if the urban areas are small) and as district boundaries (if the urban areas are large). The study areas are selected in such a way that each belong to different agro-climatic zones, hence the natural land cover types of them vary greatly from one another. The study areas are as follows:

1. Ernakulam district, Kerala. (02-03-2021)
2. Tirupur North & South taluks, Tamil Nadu. (02-03-2021)
3. Ludhiana taluk, Punjab. (30-03-2021)
4. Bangalore district, Karnataka. (02-03-2021)

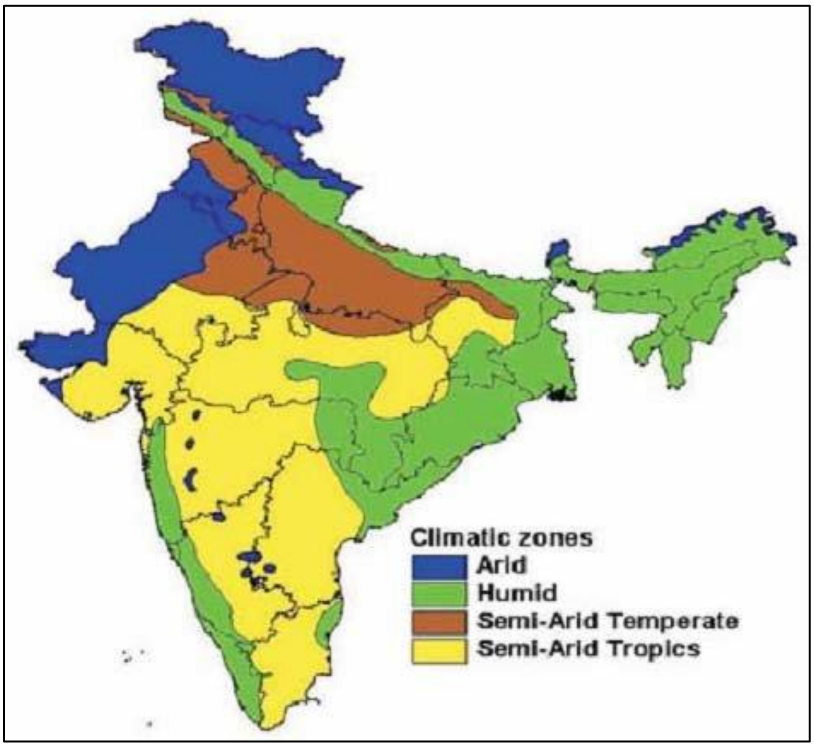



*Figure 4.1.1: Agro-climatic zones of India.*

## 4.2. Ernakulam:

The Ernakulam District is situated in Central Kerala in India. Ernakulam is located at 9.98°N 76.28°E. The district encompasses Kochi-Ernakulam urban agglomeration which is the largest urban area in Kerala. Under the Agro-climatic zones, the city of Kochi features a humid region. Since the region lies in the south western coastal state of Kerala, the climate is tropical, with only minor differences in temperatures between day and night, as well as over the year. Because of these reasons it has been selected as study area.

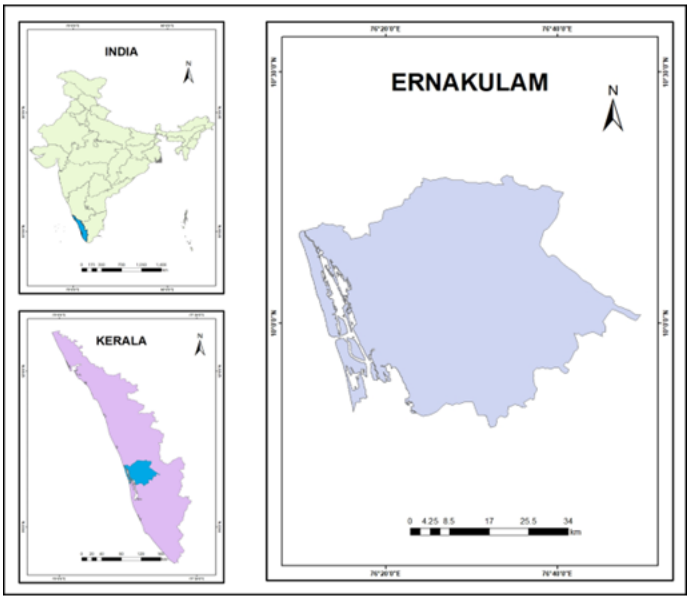



*Figure 4.2.1: Location of Ernakulam in Kerala.*

## 4.3. Tirupur:

Tirupur is located at the western part of Tamil Nadu. It is the fifth largest city as well as an urban agglomeration in Tamil Nadu. Tirupur is located at 11.1075°N 77.3398°E on the banks of the Noyyal River which divides the city into two halves. It has an average elevation of 295 metres (967 feet). The climate in Tirupur is hot semi-arid. Since the city lies in the leeward side of western ghats, it receives less rainfall during SW monsoon.

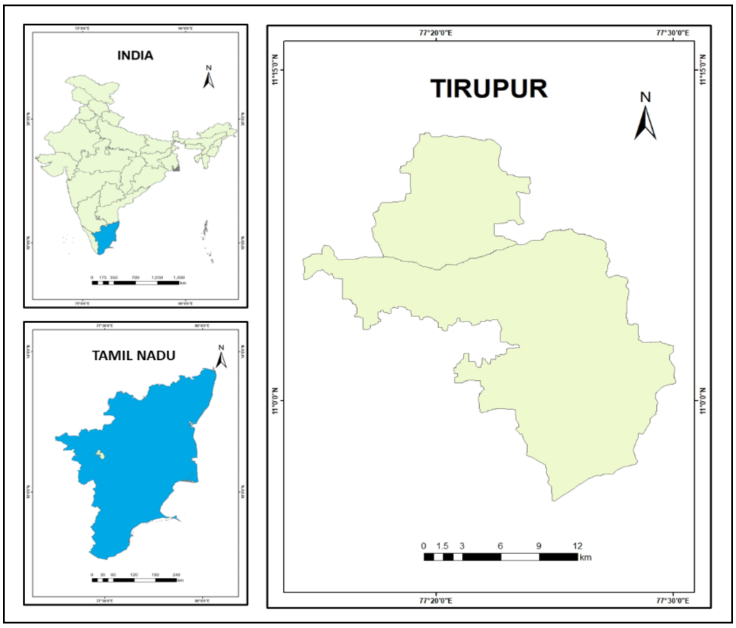



*Figure 4.3.1: Location of Tirupur North & South taluks in Tamil Nadu.*

## 4.4. Ludhiana:

Ludhiana is the most populous and the largest city in the state of Punjab. It is a major industrial centre of northern India and referred as the Manchester of India. Ludhiana is located at 30.9°N 75.85°E. It has an average elevation of 244 metres (801 ft). Ludhiana is a hot semi-arid temperate region under agro-climatic zones, but the surrounding rural areas is intensely irrigated by canal irrigation system.

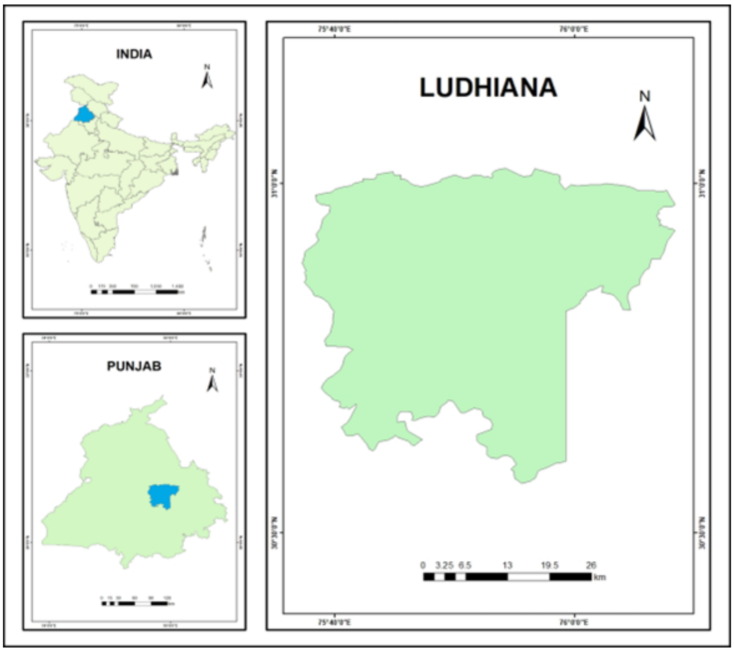



*Figure 4.4.1: Location of Ludhiana in Punjab, India.*

## 4.5. Bangalore:

Bangalore is the capital and largest city of the state of Karnataka. It is the fifth most populous urban agglomeration in India and largest city in South India. It is located at 12°58′44″N 77°35′30″E and covers 741 km$^2$. It has an average elevation of 900 metre (3000 feet). Bangalore falls under the semi-arid tropics in agro-climatic zones, but due to its high elevation, it has moderate temperature.

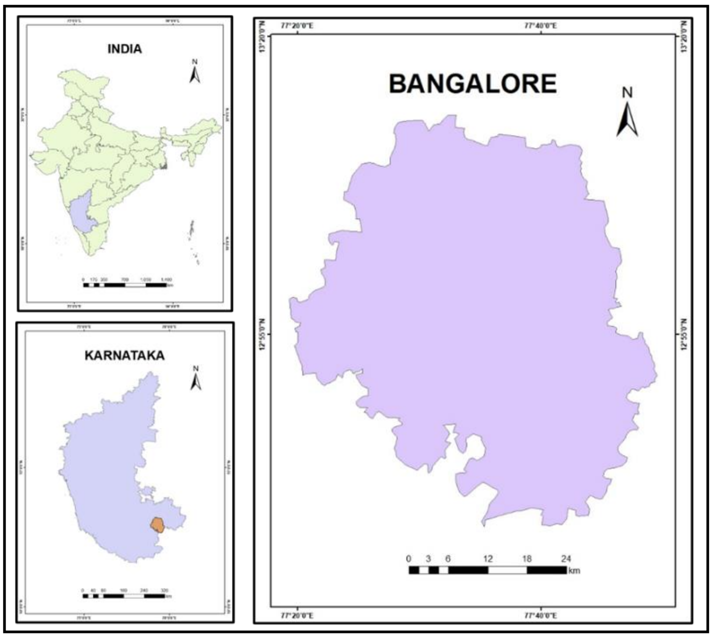



*Figure 4.5.1: Location of Bangalore in Karnataka, India.*

# CHAPTER-4: METHODOLOGY

## 5.1. General:

For our study, we used the basic Remote Sensing principles (which is measuring and recording of electromagnetic energy reflected from or emitted by the earth's surface and atmosphere from a vantage point above the surface, and relating such measurements to the nature and distribution of surface materials and atmosphere. The reflectance characteristic of earth's surface features may be quantified by measuring the portion of incident energy that is reflected. To understand this, we need to know about Electromagnetic Spectrum and various rays present in it.

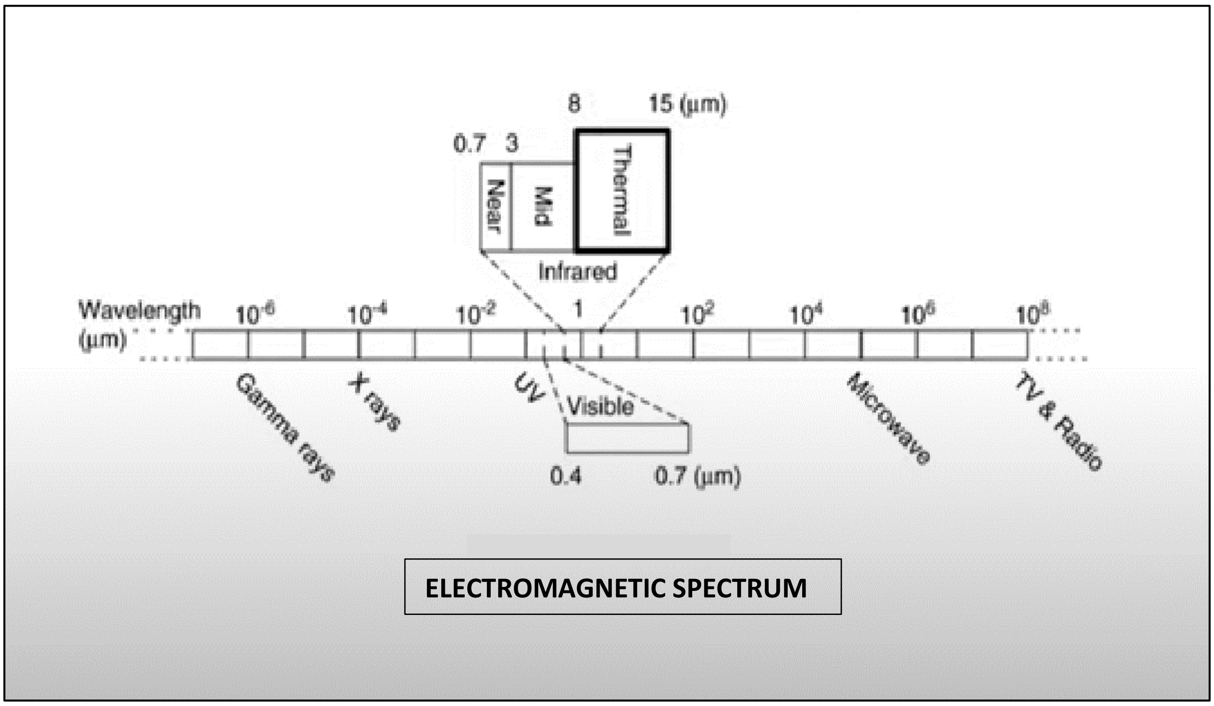



*Figure 5.1.1: Electromagnetic Spectrum*

Above figure shows that the Electromagnetic Spectrum includes wide range of radiation starting from Gamma rays to Radio-wave Radiation. However, in Remote Sensing we use only visible light, Infrared, Microwave and Radio-wave region of Spectrum, because these waves are not or less affected by the earth's atmosphere.

## 5.2. Electromagnetic Spectral Regions:

| Region | Wavelength | Remarks |
|---|---|---|
| Gamma ray | <0.03 nm | Incoming radiation is completely absorbed by the upper atmosphere and is not available for remote sensing. |
| X-ray | 0.03 to 3.0 nm | Completely absorbed by atmosphere. Not employed in remote sensing. |
| Ultraviolet | 0.3 to 0.4 µm | Incoming wavelengths less than 0.3 µm are completely absorbed by ozone in the upper atmosphere. |
| Photographic UV band | 0.3 to 0.4 µm | Transmitted through atmosphere. Detectable with film and photodetectors, but atmospheric scattering is severe |
| Visible | 0.4 to 0.7 µm | Imaged with film and photodetectors. Includes reflected energy peak of earth at 0.5 µm. |
| Infrared | 0.7 to 1.00 µm | Interaction with matter varies with wave length. Atmospheric transmission windows are separated. |
| Reflected IR band | 0.7 to 3.0 µm | Reflected solar radiation that contains information about thermal properties of materials. The band from 0.7 to 0.9 µm is detectable with film and is called the photographic IR band. |
| Thermal IR band | 3 to 5µm band | Principal atmospheric windows in the 8 to 14IJm thermal region. Images at these wavelengths are acquired by optical mechanical scanners and special vidicon systems but not by film. Microwave 0.1 to 30 cm longer wavelengths can penetrate clouds, fog, and rain. Images may be acquired in the active or passive mode. |

| | | |
|---|---|---|
| Radar | 0.1 to 30 cm | Active form of microwave remote sensing. Radar images are acquired at various wavelength bands. |
| Radio | >30cm | Longest wave length portion of electromagnetic spectrum. Some classified radars with very long wavelengths operate in this region. |

*Table 5.2.1: Electromagnetic spectral regions (Sabines, 1987)*

By the above table it is clear that we can use only certain section of Electromagnetic spectrum for geo-spatial studies. Even among them, we use only the below mentioned regions of the spectrum for our study.

- Visible & NIR – LULC studies
- Red band & SWIR – NDVI calculation
- NIR & SWIR – NDMI calculation
- TIR – LST estimation

## 5.3. Software used:

In this study we have used various geo-spatial techniques like digitizing, image processing, image classification, etc using various software at different levels to get different types of maps like LULC, LST, NDVI, NDMI, and their respective graphs. The software using which these maps and graphs have been prepared are listed below;

- ArcMap 10.8
- QGIS Desktop
- MS-Excel

## 5.4. Data Acquisition:

All the satellite data of the study areas are acquired from the high resolution (30m) Landsat 8 satellite (which has the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS)) through USGS Earth Explorer website (https://earthexplorer.usgs.gov). These data of the study areas were downloaded for the summer months (March, April, May) of the year 2021 with the scene size of 185km x 180km.

The India shapefile, which is the vector data was downloaded from the DIVA-GIS website (https://www.diva-gis.org). these shapefiles are used to extract national, state, district and taluk level boundaries from the satellite images which are raster data.

## 5.5. Landsat 8 Band Information:

| Band Number | Name | Wavelength (μm) | Resolution |
|---|---|---|---|
| 1 | Coastal | 0.433–0.453 | 30 m |
| 2 | Blue | 0.450–0.515 | 30 m |
| 3 | Green | 0.525–0.600 | 30 m |
| 4 | Red | 0.630–0.680 | 30 m |
| 5 | NIR | 0.845–0.885 | 30 m |
| 6 | SWIR 1 | 1.560–1.660 | 30 m |
| 7 | SWIR 2 | 2.100–2.300 | 30 m |
| 8 | Pan | 0.500–0.680 | 15 m |
| 9 | Cirrus | 1.360–1.390 | 30 m |
| 10 | TIRS 1 | 10.6–11.2 | 100 m |
| 11 | TIRS 2 | 11.5–12.5 | 100 m |

Credit: NASA

Table 5.5.1: Landsat-8 Bands

## 5.6. Data Processing:

The data acquired from the USGS website are raw data which have to be processed to get the desired map. For this image processing we will use QGIS software. The Semi-automatic Classification Plugin (SCP) in QGIS allows for the conversion of Landsat 8 images from DN (i.e., Digital Numbers) to the physical measure of Top of Atmosphere reflectance (TOA), or the application of a simple atmospheric correction using the DOS1 method (Dark Object Subtraction 1), which is an image-based technique.

This atmospherically corrected individual bands of Landsat 8 (band 2 to band 7) are then stacked together to get a single composite (multi-band) image which can be used for visual interpretation of surface features such as buildings, roads, vegetation, water, etc. Using this multi-band image, we can make different colour composite images which help to identify the features more readily. Some of them are mentioned in the table below;

| ***Composite Name*** | ***Band Combination*** |
|---|---|
| *Natural Colour* | *4 3 2* |
| *False Colour (urban)* | *7 6 4* |
| *Colour Infrared (vegetation)* | *5 4 3* |
| *Agriculture* | *6 5 2* |
| *Atmospheric Penetration* | *7 6 5* |
| *Healthy Vegetation* | *5 6 2* |
| *Land/Water* | *5 6 4* |
| *Natural With Atmospheric Removal* | *7 5 3* |
| *Shortwave Infrared* | *7 5 4* |
| *Vegetation Analysis* | *6 5 4* |

*Credit: ESRI*

*Table 5.6.1: Band Combinations.*

## 5.7. Image classification:

Once image processing is done, the next step will be classification of image. Image classification refers to the task of extracting information classes from a multiband raster image. In other words, image classification is a procedure to categorize all pixels in an image of a terrain into land cover classes. The resulting raster from image classification can be used to create thematic maps. Depending on the interaction between the user and the computer during classification, there are two types of classification:

- Supervised classification
- Unsupervised classification.

Supervised classification uses the spectral signatures obtained from training samples which are given by the user, to classify an image. Whereas the unsupervised classification finds spectral classes (or clusters) in a multiband image without the user's intervention. in this study we have used supervised classification in SCP plugin of QGIS to classify the image.

As mentioned earlier for supervised image classification we have to give the training data. Using SCP plugin, the training data of four classes namely, barren land, buildup, vegetation and water body from all over the area of interest have been created for all the study area. Using this training data, the Supervised image classification has been made by Minimum distance method.

Minimum distance classification is one of a simple algorithm. Here all pixels in image classified according to the class mean to which they are closest. the use of a training set of a class is represent as a center point based on the information about the average of all pixels of sample class. This method calculates the mean vector for each class, calculate the statistical (Eulidean) distance from each pixel to class mean vector and assign each pixel to the class it is closed. The minimum distance classification is based on the minimum distance from the mean value of each class of the training data to the digital value of each pixel in the imagery. The minimum distance is calculated by using the Euclidean distance measurement.

Once the image classification is done, these classified images are then cropped to study area extent with the help of respective shapefiles (vector data), which was then used to create the LULC maps of all the study areas.

# LULC Maps of Study Areas

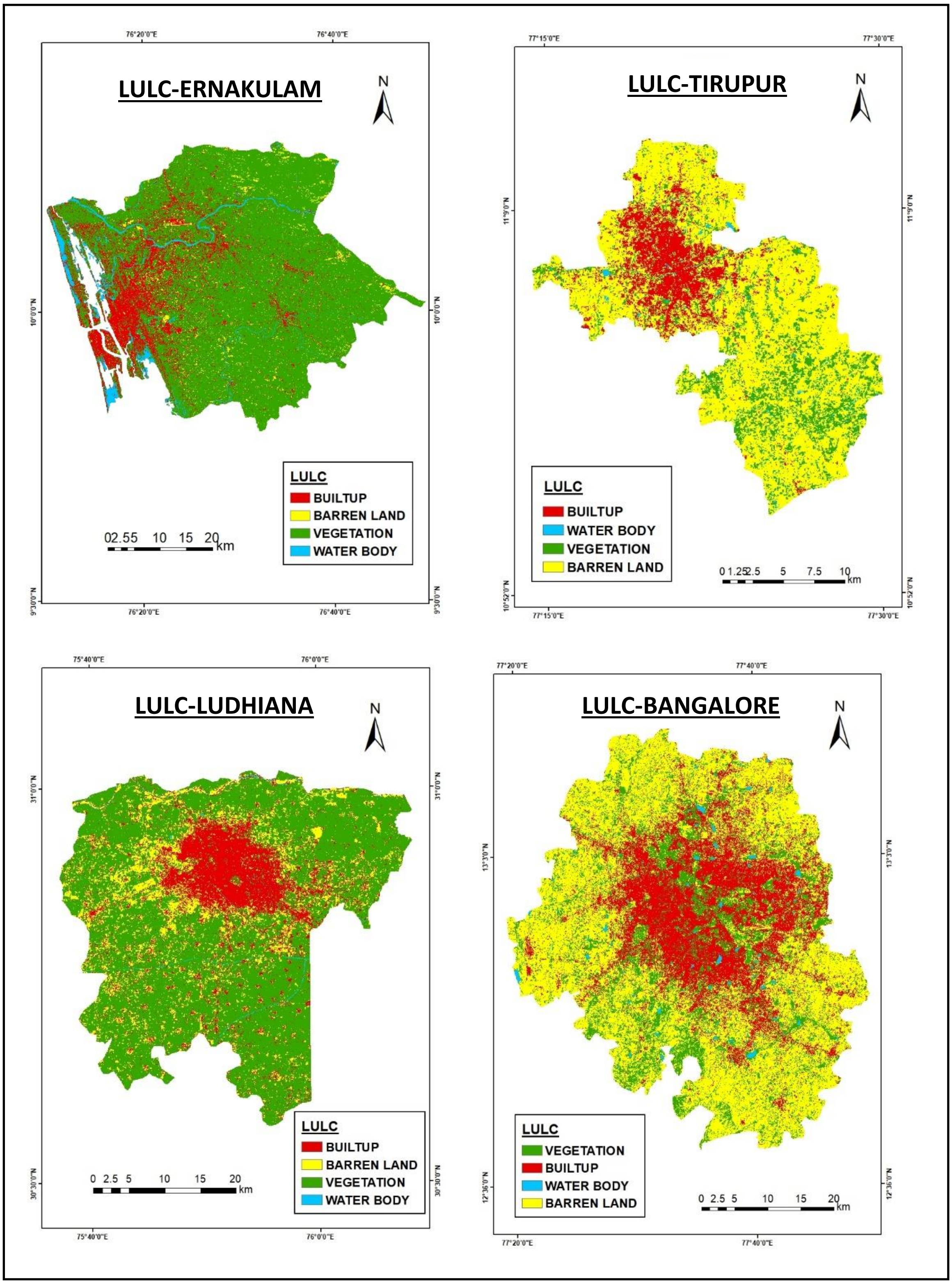



*Figure 5.7.1: LULC maps of Ernakulam, Tirupur, Ludhiana & Bangalore.*

## 5.8. <u>Creation of LST maps</u>:

We know that the earth emits Electromagnetic radiation in infrared wavelength. The Thermal Infrared (TIR) wavelengths between 8 to 15 micrometers emitted by the earth are commonly used for LST estimation. Around 10-12 micrometers the atmosphere has relatively low absorption of IR radiation emitted by the land surface. This phenomenon is called Atmospheric window, which means the atmosphere is transmissive to particular range of wavelength in the Electromagnetic Spectrum (i.e., the atmosphere won't react with the radiations of particular wavelengths). Therefore, the satellite sensors measure these infrared wavelengths to derive the Land Surface Temperature of the earth.

Thus, for the creation of Land Surface Temperature (LST) maps we use Thermal Infrared Sensors (TIRS) of the satellite images. In Landsat-8 we have two Thermal Infrared Sensors namely, TIRS-1 (band 10) and TIRS-2 (band 11) which have wavelengths of 10.6-11.2 µm and 11.5-12.5 µm respectively.

These bands aim to provide an accurate land temperature that is given as top of atmosphere surface (calibrated at-sensor) radiance convertible to equivalent brightness temperature. We can convert the brightness temperature to Celsius directly using SCP plugin in QGIS or using a formula in ArcMap. In this study we have used SCP plugin in QGIS for the preparation of LST map, which converts the TOA radiance into atmospherically corrected brightness temperature in Celsius.

If we use the derivation, the formula would be,

$$\mathbf{LST = (BT / 1) + W * (BT / 14380) * \ln(E)}$$

Where:

**BT** = Top of atmosphere brightness temperature (°C)

**W** = Wavelength of emitted radiance

**E** = Land Surface Emissivity

Since we are not using the formula, (instead used SCP plugin to calculate LST automatically) we will not discuss much about the formula.

# LST Maps of Study Areas

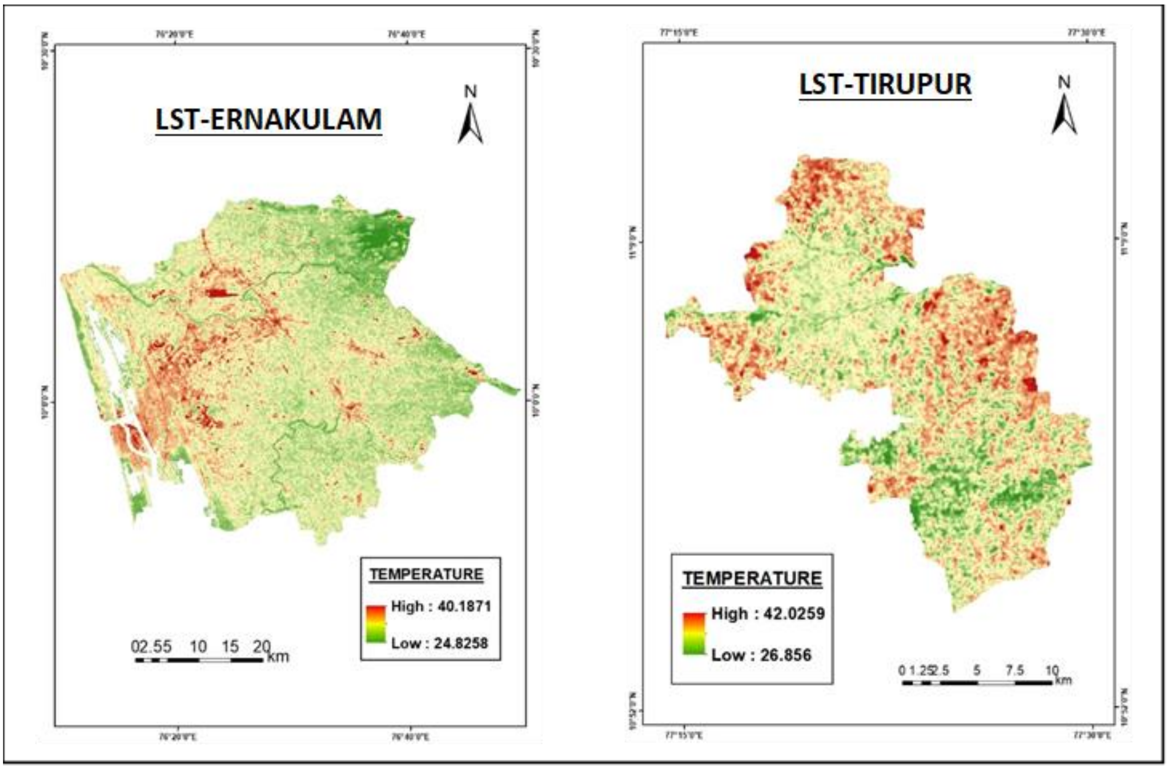



*Figure 5.8.1: LST maps of Ernakulam & Tirupur.*

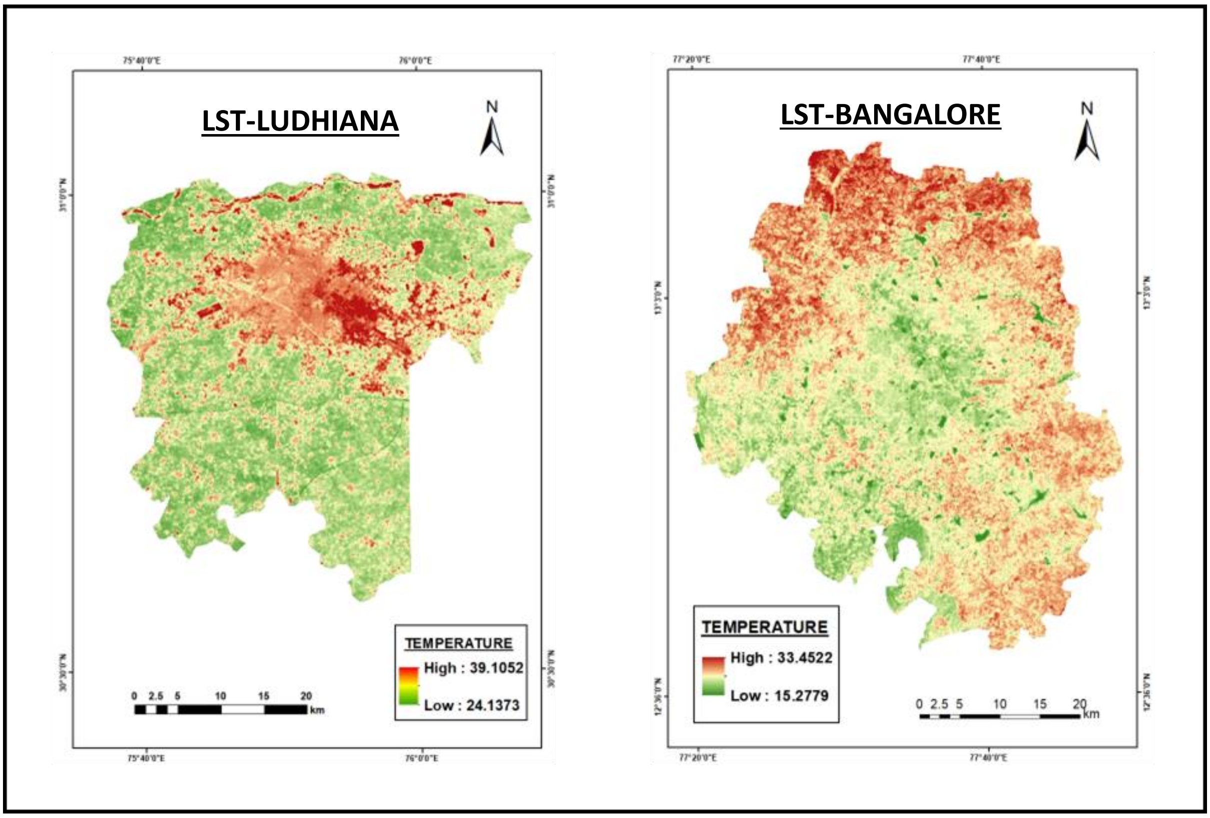



*Figure 5.8.2: LST maps of Ludhiana & Bangalore.*

## 5.9. Creation of NDVI maps:

NDVI–Normalized Difference Vegetation Index quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs). Vegetation coverage has a significant influence on the land Surface Temperature (LST) distribution. Hence, NDVI is used to examine the relation between thermal behaviour and vegetation cover amount.

The presence of chlorophyl corresponds to the healthy green vegetation and results in higher NDVI values. However, dry, or diseased or deciduous non-greenish vegetation, which can also be referred to as Non-Photosynthetic Vegetation (NPV) has different reflectance properties compared to green vegetation and result in lower NDVI values.

To calculate NDVI we use NIR and red bands of Landsat-8 which are band 5 and band 4 respectively and the formula is,

$$\text{NDVI} = \frac{NIR - Red}{NIR + Red}$$

$$\text{NDVI} = \frac{Band\ 5 - Band\ 4}{Band\ 5 + Band\ 4}$$

This NDVI is a bounded ratio that ranges between -1 to +1. Clouds, water and snow have negative NDVI since they are more reflective in visible than near IR wave lengths. Soil and rock have a broadly similar reflectance giving NDVI close to 0, Only active vegetation has a positive NDVI being typically between about 0.1 and 0.6 values at the higher end of the range indicating increased photosynthetic activity and a greater density of the canopy (Tarpley et. al 1984).

In SUHI studies, NDVI is therefore useful in identifying cooler (low LST) green rural areas (with high NDVI values) compared to hotter (high LST) sparsely vegetated or impervious built-up areas (with close to zero NDVI value).

# NDVI Maps of Study Areas

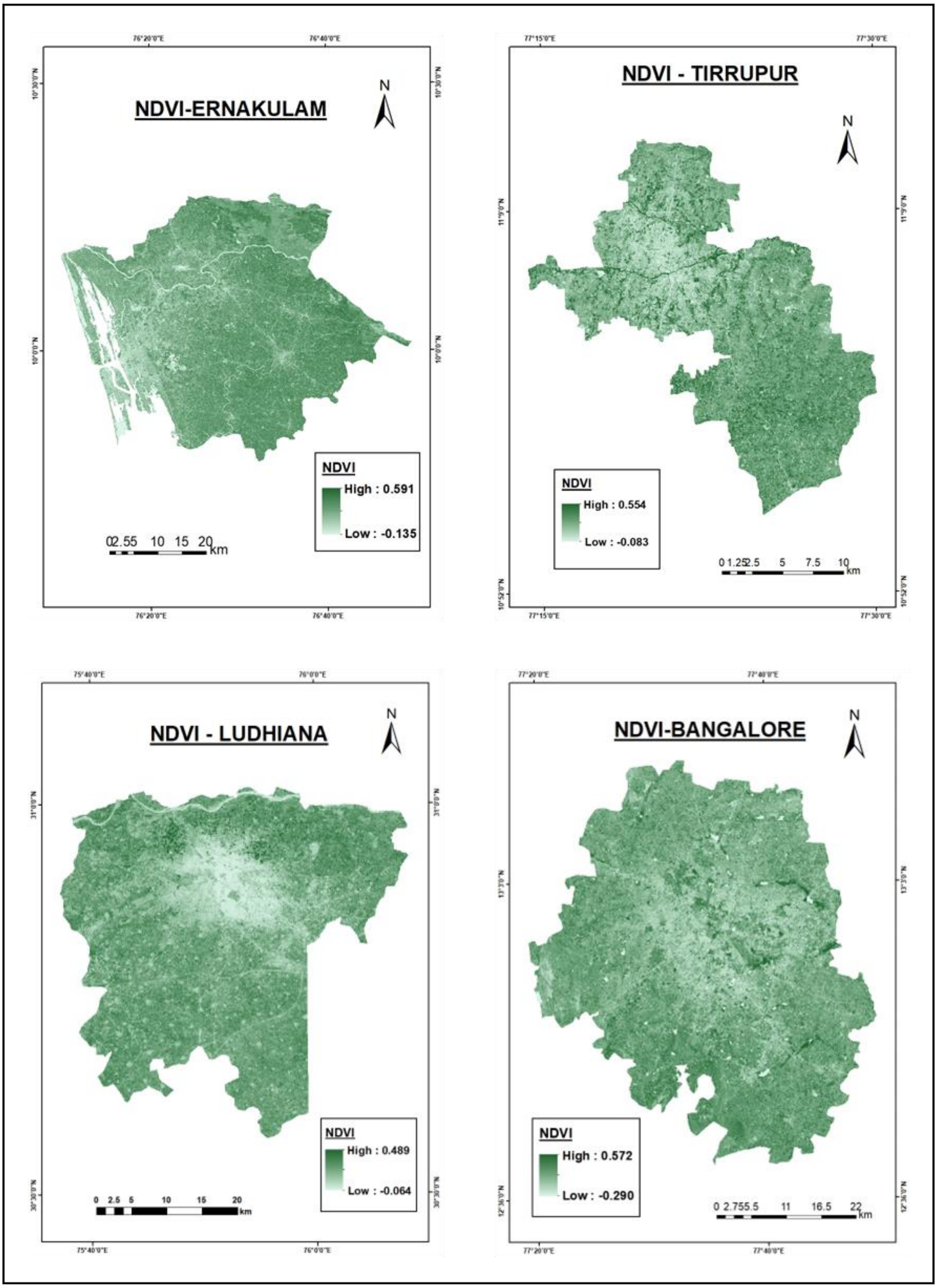



*Figure 5.9.1: NDVI maps of Ernakulam, Tirupur, Ludhiana & Bangalore.*

## 5.10. Creation of NDMI maps:

NDMI–Normalized Difference Moisture Index detects moisture levels in vegetation using a combination of near-infrared (NIR) and short-wave infrared (SWIR) spectral bands. It can also be used to locate the water bodies. To calculate NDVI we use NIR and red bands of Landsat-8 which are band 5 and band 4 respectively and the formula is,

$$\text{NDMI} = \frac{\boldsymbol{NIR-SWIR}}{\boldsymbol{NIR+SWIR}}$$

$$\text{NDMI} = \frac{\boldsymbol{Band\ 5-Band\ 6}}{\boldsymbol{Band\ 5+Band\ 6}}$$

Like NDVI, NDMI values also varies from -1 to 1. The NDMI value of different materials are listed below;

| NDMI VALUE | INTERPRETATION |
|---|---|
| (-1) – (-0.8) | Bare soil, Built-Up |
| (-0.8) – (-0.6) | Almost absent canopy cover |
| (-0.6) – (-0.4) | Very low canopy cover |
| (-0.4) – (-0.2) | Low canopy cover, dry or very low |
| (-0.2) – (0) | Mid – low canopy cover |
| (0) – (0.2) | Average canopy cover |
| (0.2) – (0.4) | Mid-high canopy cover |
| (0.4) – (0.6) | High canopy cover, no water stress |
| (0.6) – (0.8) | Very high canopy cover, no water stress |
| (0.8) – (1) | Total canopy cover, no water stress/ waterlogging |

*Table 5.10.1: NDMI Index*

# NDMI Maps of Study Areas

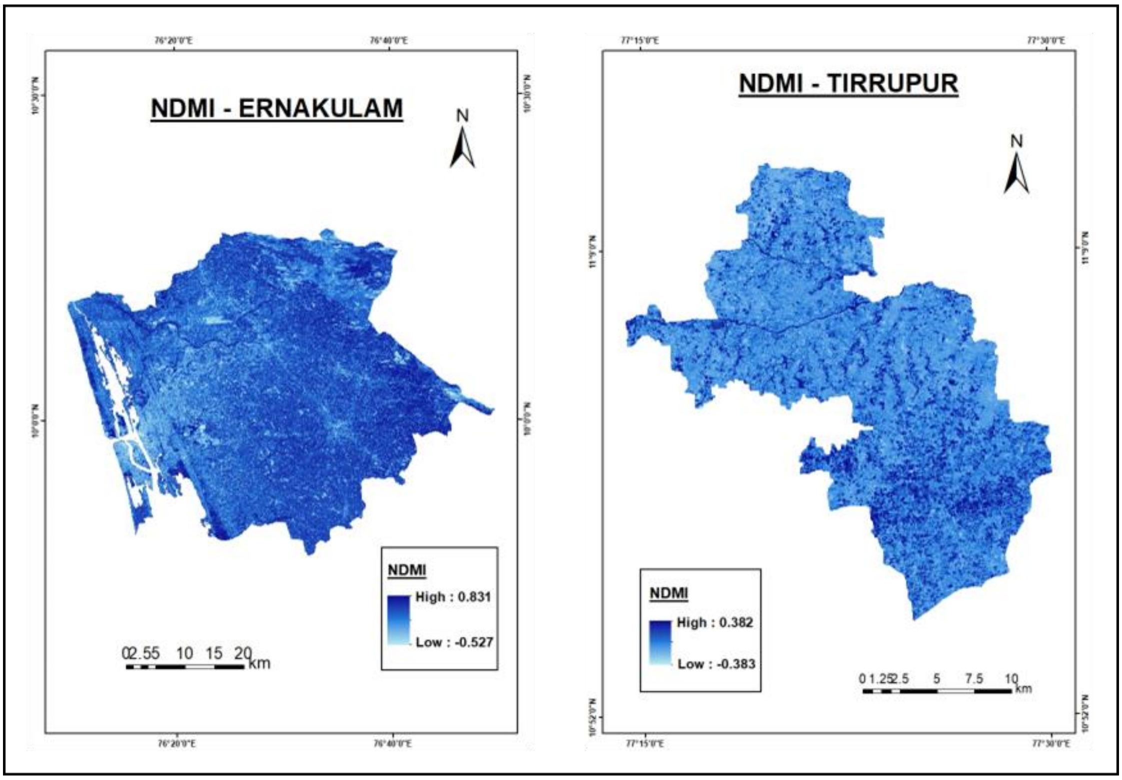



Figure 5.10.1: NDMI maps of Ernakulam & Tirupur

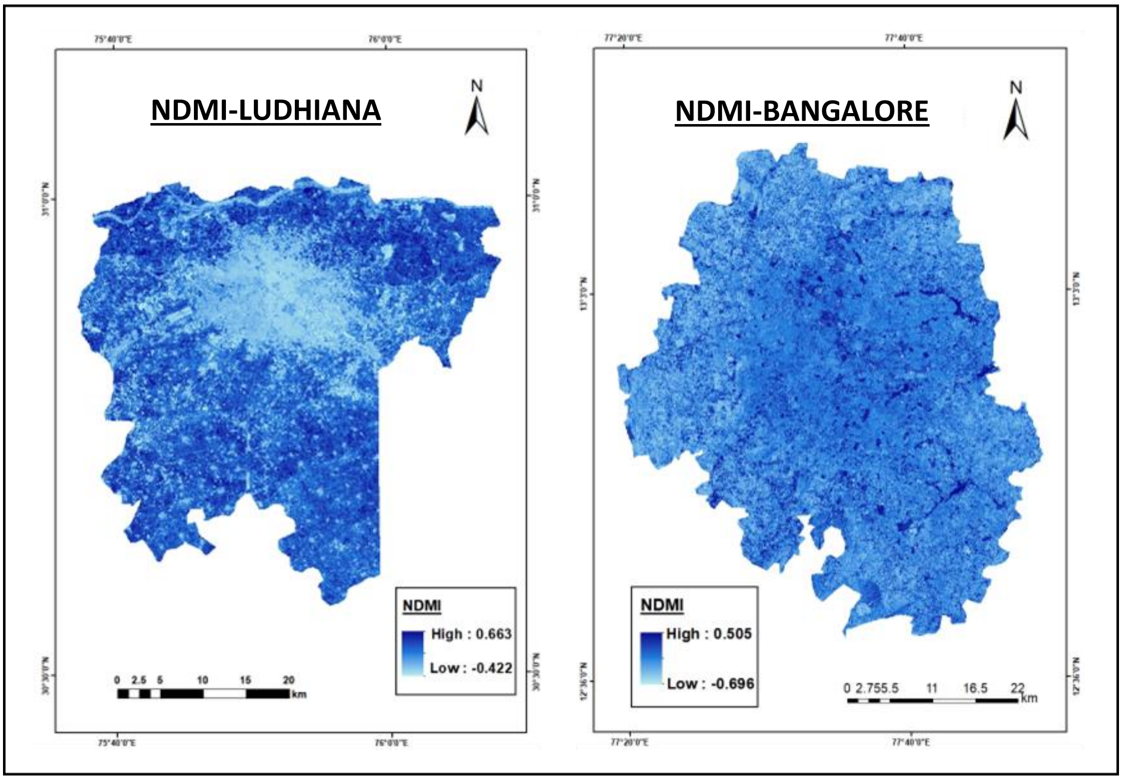



Figure 5.10.2: NDMI maps of Ludhiana & Bangalore.

# CHAPTER-5: RESULTS

## 6.1. Correlation between LULC & LST:

### 5.1.1. Ernakulam:

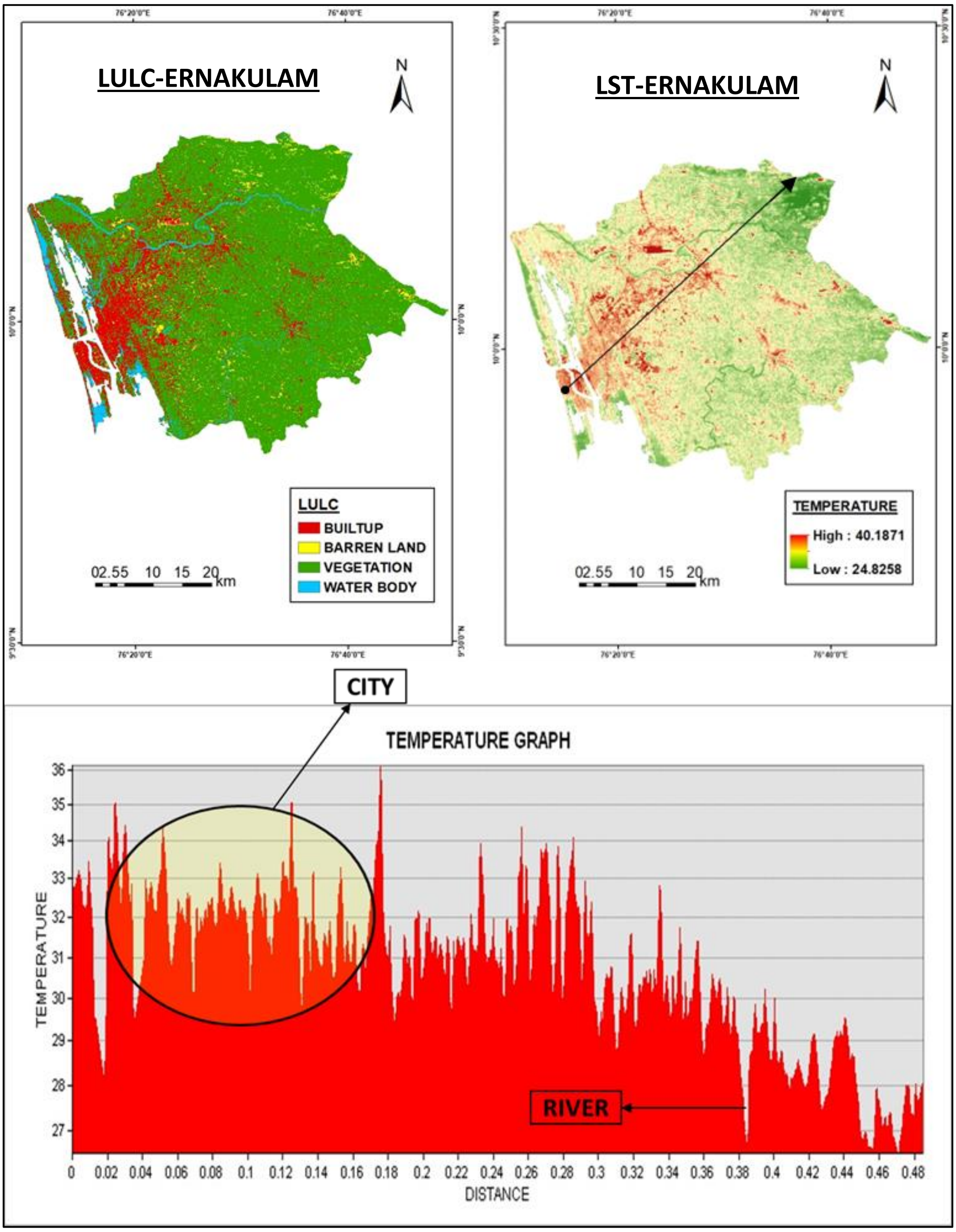



Figure 6.1.1: LULC map, transect line superimposed on LST map & the temperature graph (Ernakulam).

**INTERPRETATION:**

In the Land Surface Temperature (LST) map of Ernakulam a transect line is drawn using Stack profile tool in ArcMap which will extract the temperature of the pixel at a regular interval. This transect line is drawn in such a way that it will start from the city area and ends in the forest (western ghats) bisecting the river along its path. Then using these temperature values, a graph is created for interpretation.

The above maps of Ernakulam (Figure.5.1.1) show the typical characteristics of **'Urban Heat Island' (UHI)** effect where the built-up areas have experienced higher temperature than the rural counterparts. When we examine closely, the temperature along the transect line (which gives us the temperature valve of the pixel) there is marked increase in temperature in Kochi-Ernakulam urban agglomerate (around 32°C), while it drops gradually as we move towards rural areas (around 30°C). Further in the river and forest area the temperature drops below 27°C.

As the study area (Ernakulam district) falls under the humid climatic region, the areas other than buildings, roads and water bodies are entirely covered by vegetation for the entire year and the vegetation do not shed their leaves during the summer months as they belong to tropical evergreen forest. This is due to the fact that this region receives rainfall throughout the year except in winter months (even during which the temperature will be low) because they are in the windward side of Western ghats.

Because of the above reasons, the vegetation remains green throughout the year. These vegetations and the water bodies absorbs energy from the sun which is released back into the atmosphere in the form of water vapour through the evapo-transpiration process, thus, remaining cooler. Whereas the urban materials such buildings, roads, etc. absorb the sun's energy and emit it back in the form of heat energy, thereby increasing the temperature of the area. This led to the increased temperature in the urban area.

Therefore, the Ernakulam-Kochi urban agglomerate experiences the Urban Heat Island (UHI) effect by having hotter urban region and cooler rural surroundings, due to the above-mentioned reasons.

## 5.1.2. Tirupur:

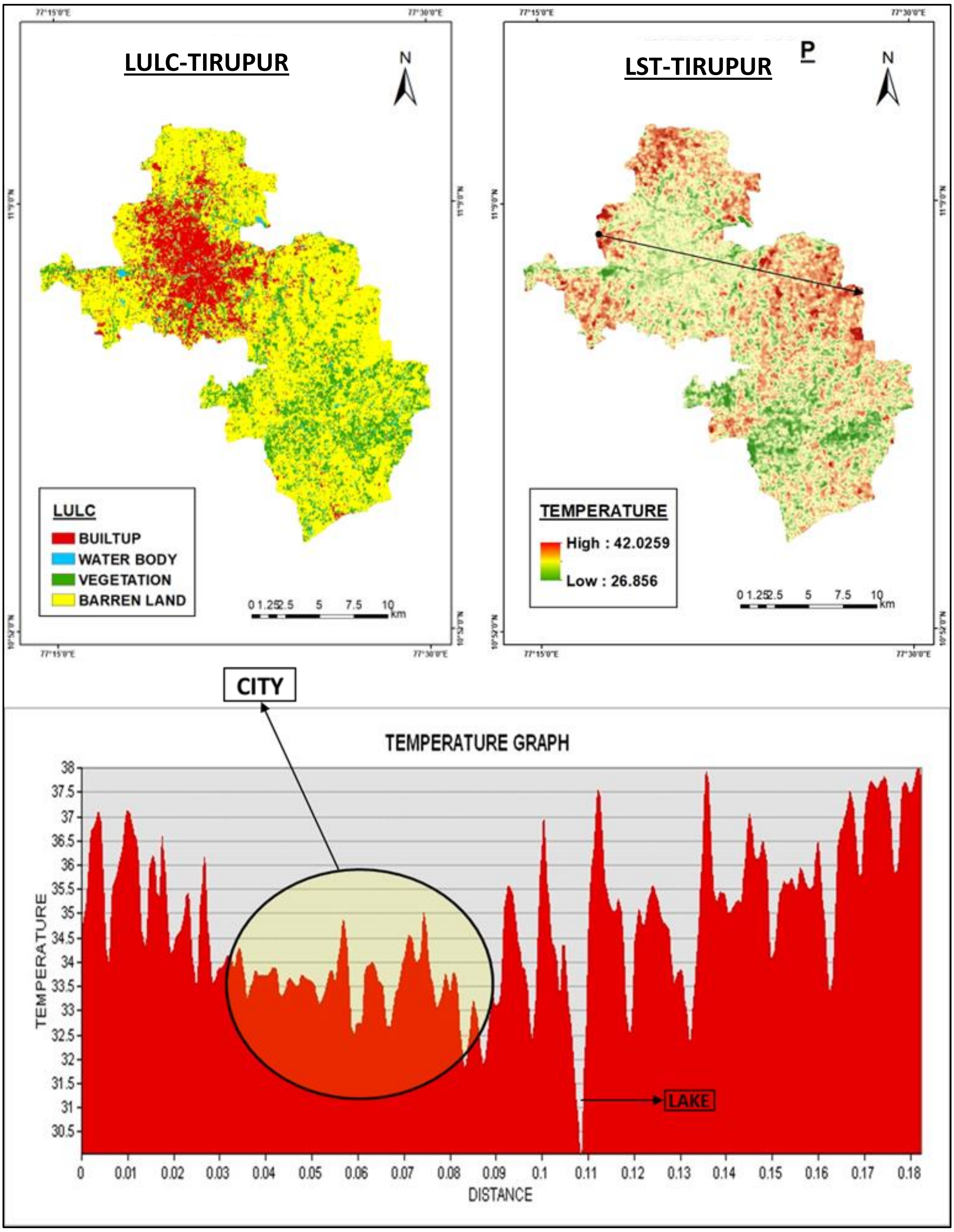



*Figure 6.1.2: LULC map, transect line superimposed on LST map & the temperature graph (Tirupur).*

**INTERPRETATION:**

In the LST map of Tirupur a transect line is drawn in such a way that it will start from the barren land in the western side of the city and ends in barren land in eastern part of the city passing through the city and the river along its path. Then using these temperature values, a graph is created for interpretation.

In the Figure 5.2.1 we can observe that there is no Urban Heat Island (UHI) effect, on the contrary we could see **'Urban Cool Island' (UCI)** i.e., the urban area in cooler than rural surroundings. When we analyze through the transect line, the temperature is high in the rural barren land (around 36°C). As the line passes through the city, the temperature drops to 34.5°C and even reaches to 32°C in the middle of the city due to the presence of vegetation in the dried-up river channel. The minimum temperature of 30°C is recorded in the lake. This is due to the reasons as mentioned below;

The Tirupur city comes under Semi-arid climatic region, or steppe climate that receives precipitation below potential evapotranspiration, but not as low as a desert climate. Thus, the agriculture greatly relied on ground water for irrigation. The over exploitation of ground water due to green revolution led to its depletion. Hence the surrounding rural area which is mostly agricultural land remains barren or covered by little vegetation for most part of the year.

The **thermal admittance** (m, ability of the surface to accept or release heat), **thermal diffusivity** (K, ability of the material to diffuse heat), and **heat capacity** (C, amount of heat required to change temperature by 1 K) of the dry clay or peat (soil type in croplands of India) are lower compared to concrete that predominates in Indian urban built-up areas *(Oke, 1987).* This means that concrete has a higher capability to transfer heat and require more heat to change temperatures compared to dry soil, and so during daytime built-up areas are likely to have lower LSTs compared to dry and sparsely vegetated croplands in rural areas as they can absorb the sun's radiation and re-emit it in the form of heat more readily than the urban materials.

Because of the above-mentioned reasons, we have observed Urban Cool Island (UCI) in Tirupur, where the urban area is cooler than the rural surroundings rather than the Urban Heat Island (UHI), where the urban area will be hotter than the rural counterparts.

## 5.1.3. Ludhiana:

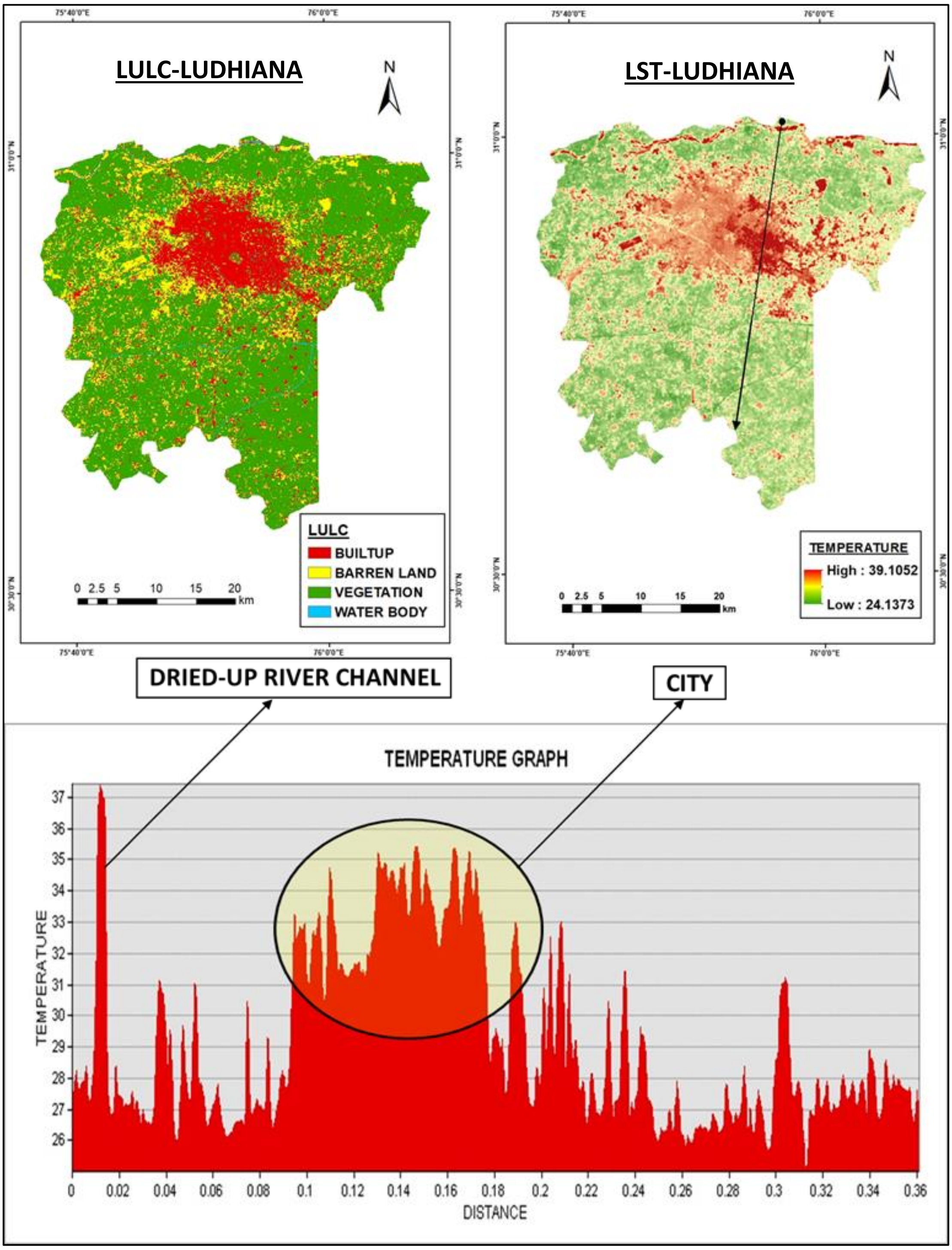



Figure 6.1.3: LULC map, transect line superimposed on LST map & the temperature graph (Ludhiana).

**INTERPRETATION:**

In the LST map of Ludhiana a transect line is drawn in such a way that it will start from the agricultural land in northern side of the city and ends in the agricultural land in southern part of the city passing through the river channel, city and the canals along its path. Then using these temperature values, a graph is created for interpretation.

The figure 5.3.1 of Ludhiana shows the **'Urban Heat Island'** (UHI) effect. As we observe closely through the transect line, the temperature is lower in the rural agricultural lands (around 27°C) and a little spike within the rural land is due to the fallow agricultural land. When the line passes through the city, the temperature increases drastically to 32°C and even reached 35°C. The sudden dip in temperature to its minimum near the end of transect line is because of water in the irrigation canal. At the beginning of the line, we can notice the spike in temperature, which is also the maximum temperature (above 37°C) is due the sand in dried up river channel.

Even though the Ludhiana falls under Semi-arid climatic region (like Tirupur), it does not have Urban Cool Island (UCI) as in Tirupur. This is due to the dense canal irrigation system, which lead to intense agriculture in the area. Hence the rural lands are covered by green vegetation all-around the year which emits less heat than the city region, whereas in Tirupur rural areas predominantly barren or covered by sparse vegetation which emits more heat than the city region.

Another difference between Tirupur and Ludhiana is the temperature of dried up river channel, as the former has low temperature in the channel than the surroundings because the vegetation covers the channel which emits less heat than the city region, while the latter has high temperature in the channel than the surroundings because the channel is predominantly filled with barren sand which emits the heat more rapidly.

The analysis of LST map shows that the eastern part of the city is hotter than the rest of the city, which is due to the concentration of heavy industries in this region. Hence in spite of being in the semi-arid region, due to intense agricultural practices, the Ludhiana experiences the Urban Heat Island (UHI), as the urban region is hotter than the rural surroundings.

## 5.1.4. Bangalore:

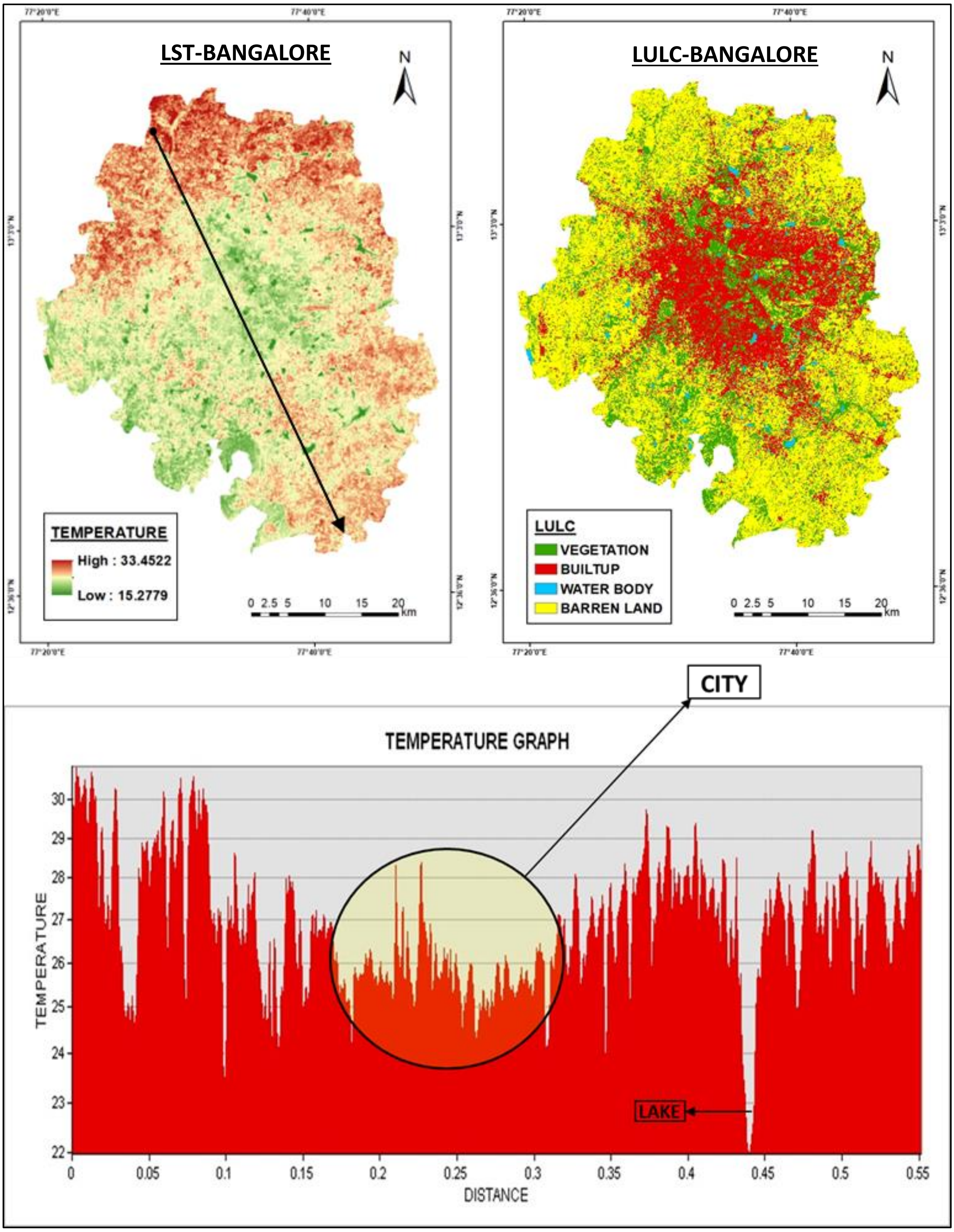



*Figure 6.1.4: LULC map, transect line superimposed on LST map & the temperature graph (Bangalore).*

**INTERPRETATION:**

In the LST map of Bangalore a transect line is drawn in such a way that it will start from the barren land in the north-western part of the city and ends in barren land in south-eastern part of the city passing through the city, parks and lake along its path. Then using these temperature values, a graph is created for interpretation.

By analyzing the figure 5.4.1, we can interpret that Bangalore (like Tirupur) shows **'Urban Cool Island'** (UCI) effect instead of Urban Heat Island (UHI). As we see through the transect line, we can observe high temperature (between 27°C and 29°C) in the rural barren land and the temperature decreases below 26°C in the city region. The Minimum temperature (22°C) is observed in lake.

The only difference between Bangalore and Tirupur is the mean temperature of the two regions. The average temperature of Tirupur is of 34°C whereas Bangalore has 27°C as average temperature. This is due to the difference in the altitude of the two regions as the altitude of Bangalore is 900 meters and that of Tirupur is 295 meters. The temperature decreases with increase in altitude, so the Bangalore has low temperature when compared with the temperature of Tirupur.

Like Tirupur, the Bangalore has rural area covered by fallow agricultural land or sparse vegetation which absorbs the sun's energy and radiate it back in the form heat energy like impermeable urban materials but in a faster rate due to their thermal properties such as thermal admittance, thermal diffusivity and heat capacity. Also, the Bangalore city area has more parks and lakes which helps to lower the city temperature. This led to the relatively high temperature in rural region than the urban area.

Hence like Tirupur, Bangalore has an Urban Cool Island (UCI), where the urban area is relatively cooler than the rural surroundings rather than the Urban Heat Island (UHI), where the urban area will be hotter than the rural counterparts.

In the following analysis we would leave out the Bangalore study area as the Tirupur and Bangalore are similar to each other in almost every aspect.

## 6.2. Correlation between LST AND NDVI:

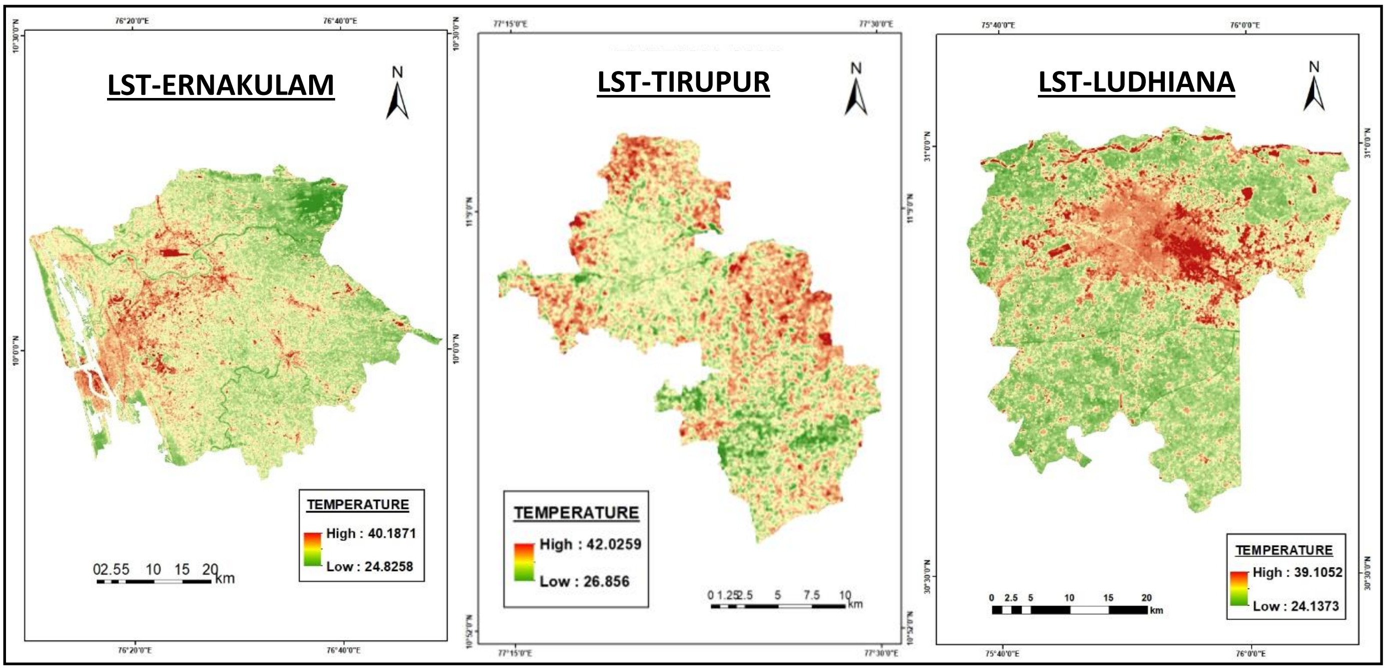



*Figure 6.2.1: LST maps of Ernakulam, Tirupur & Ludhiana.*

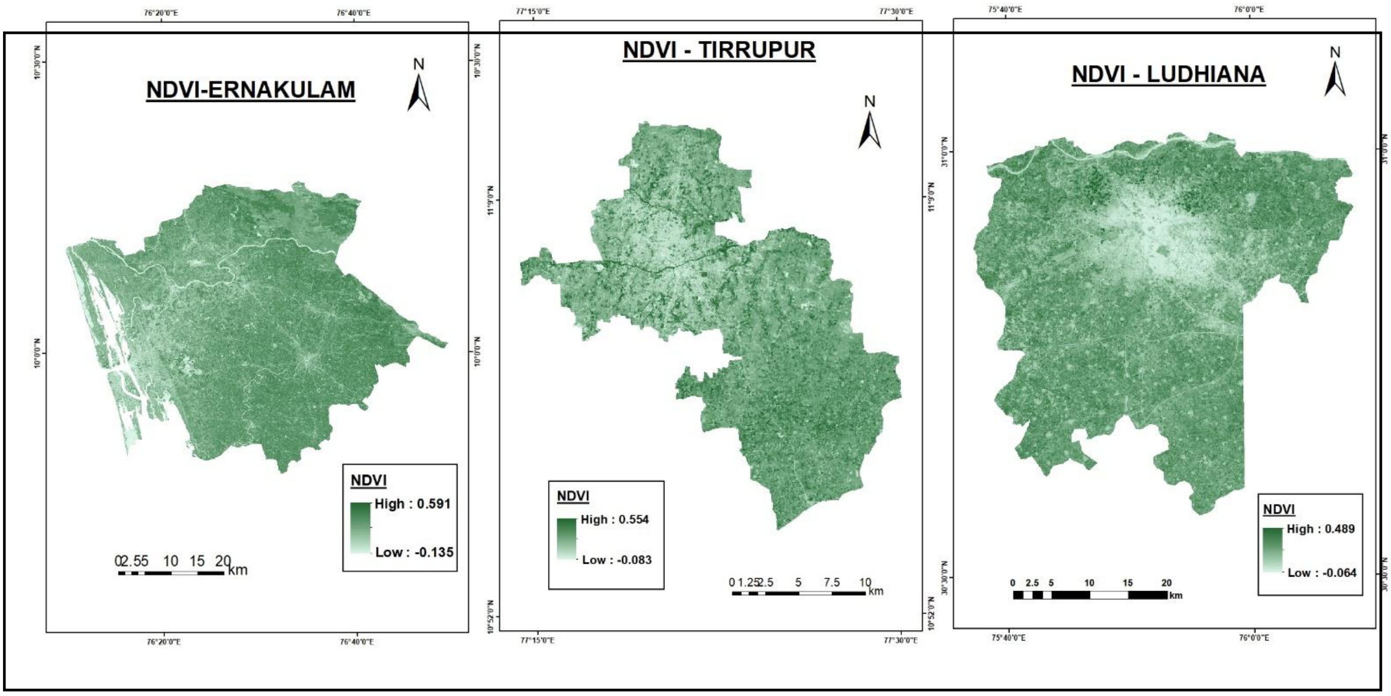



*Figure 6.2.2: NDVI maps of Ernakulam, Tirupur & Ludhiana.*

**INTERPRETATION:**

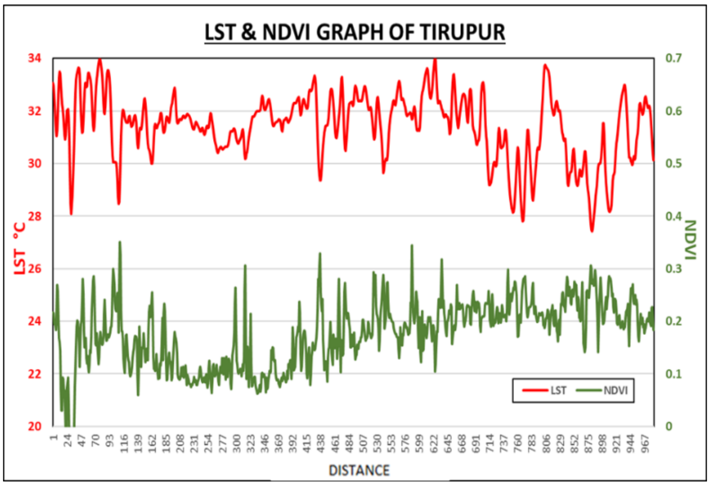
In general, Normalized Difference Moisture Index (NDVI) is useful in UHI studies for identifying cooler (low LST) green rural areas (with high NDVI values) compared to hotter (high LST) built-up areas (with close to zero NDVI value), as the NDVI represents the ratio of vegetation in each pixel. The analysis of correlation between LST and NDVI have given mixed results for different study areas.

In Ernakulam, we can observe a typical negative correlation between LST and NDVI as in conventional Urban Heat Island (UHI), i.e., LST increases with decrease in NDVI value. But there is a positive correlation between the LST and NDVI along the river (both LST and NDVI values decreases). This may lead to misinterpretation of the result.

In Tirupur, we couldn't find any marked correlation (negative or positive) between LST and NDVI. This is because of presence of dry non-photosynthetic vegetation in the rural lands of Tirupur which have more NDVI value than the built-up area. Hence, we cannot use NDVI maps for LST studies in these regions.

In Ludhiana, we have got both negative and positive correlations are present. In agricultural fields and built-up areas there is a negative correlation between LST and NDVI, whereas in irrigation channels we have positive correlation. But we could not find any correlation for barren land, because of the reason mentioned earlier.

The following graphs will give more insights to the relationship between LST and NDVI.



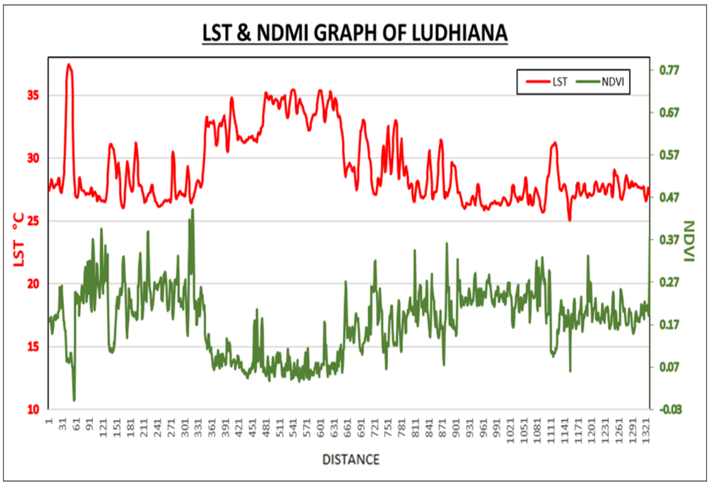




*Figure 6.2.3: LST & NDVI graphs of Tirupur & Ludhiana.*

# 6.3. Correlation between LST AND NDMI:

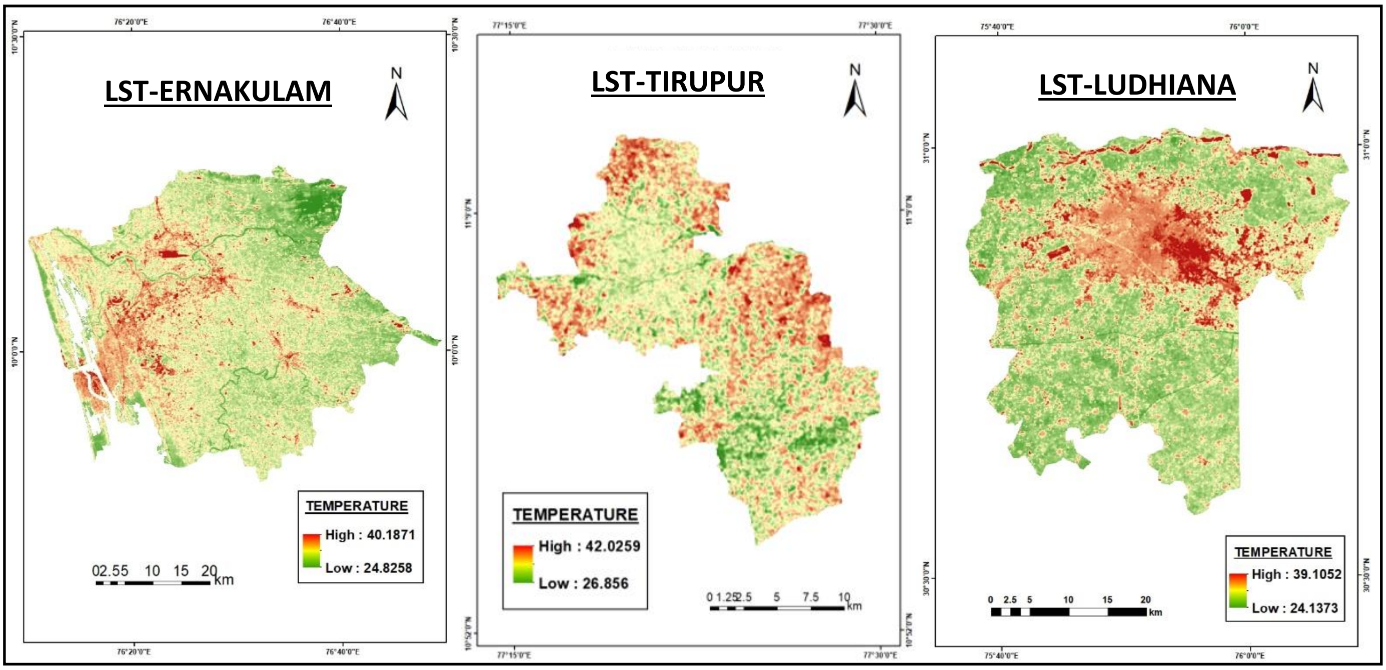



Figure 6.3.1: LST maps of Ernakulam, Tirupur & Ludhiana.

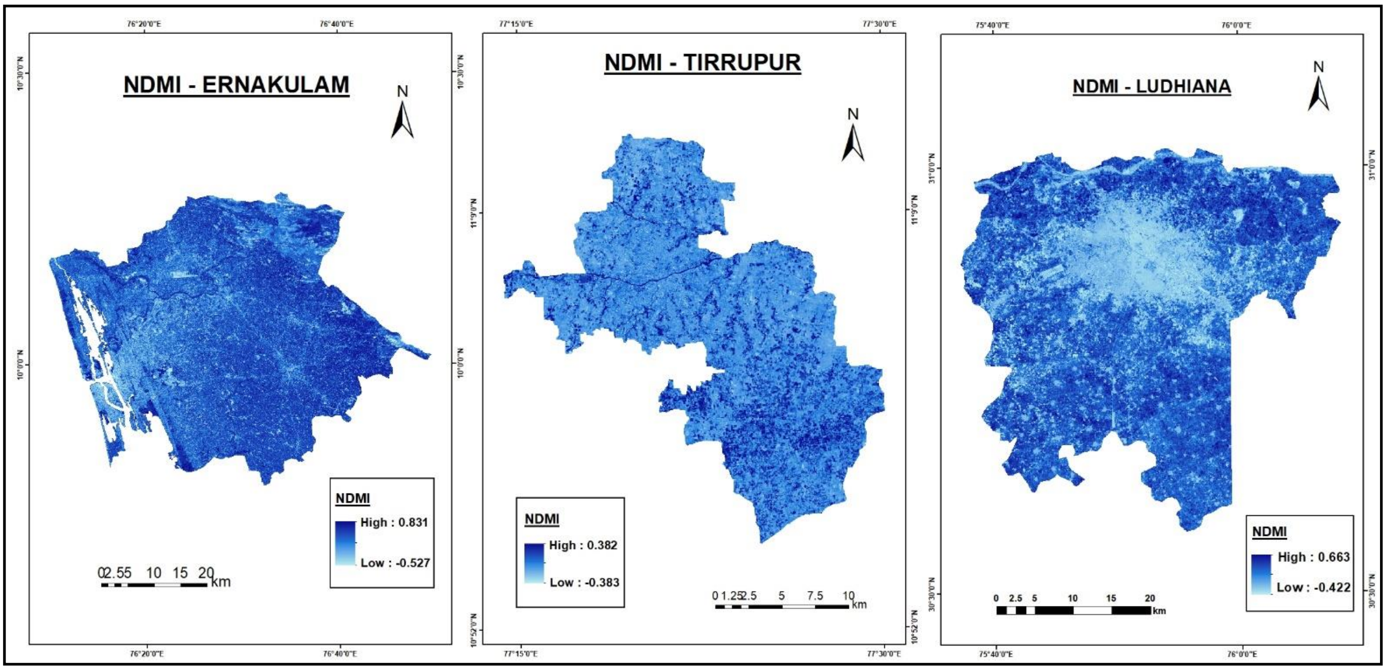



Figure 6.3.2: NDMI maps of Ernakulam, Tirupur & Ludhiana.

**INTERPRETATION:**

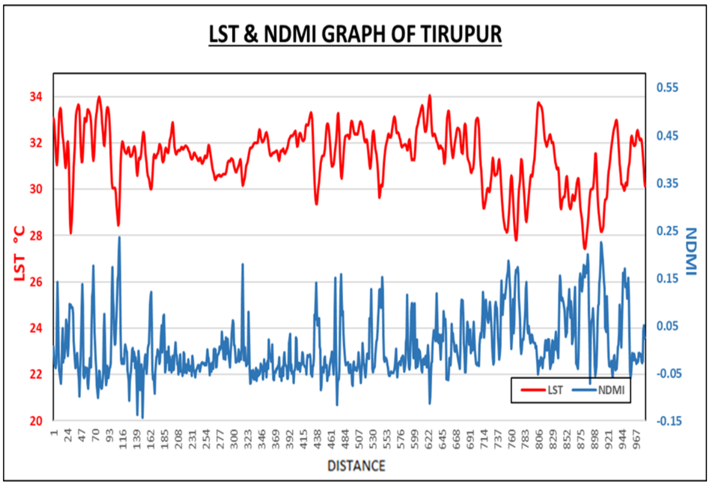
The analysis of association between LST and NDMI through the visual interpretation of figure 8.1 and 8.2 shows that there is a negative relationship between LST and NDMI. In all the study areas (Ernakulam, Tirupur & Ludhiana) there is a decreasing trend in LST with increase in moisture content (NDMI value).

In Ernakulam and Ludhiana, the NDMI is less in the city and more in the rural area whereas in Tirupur NDMI value is less both in city and in Barren rural land. This because of the following reason;

The solar energy absorbed by the vegetation and water bodies are used up in the evapo-transpiration. Through this process, vegetation and water bodies losses the absorbed energy in the form of water vapour into the atmosphere, which in turn reduces the temperature. This results in decrease in Land Surface Temperature (LST) of that region. As the barren land (dry soil) and buildings have no water for evaporation, they remain hot due the absorption of sun's energy resulting in increase in LST.

Because of the above reasons the NDMI values are high for vegetation and water bodies and low for barren land and built-up area, which led to decrease in LST for vegetation and water bodies and increase in LST for barren land and built-up area respectively. Therefore, NDMI values are directly proportional to LST.

The following graphs will give more insights to the relationship between LST and NDVI.



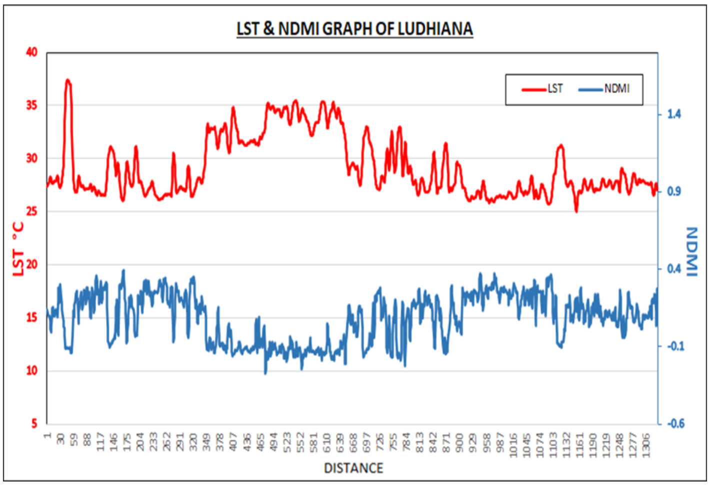




*Figure 6.3.3: LST & NDMI graphs of Tirupur & Ludhiana.*

# CHAPTER-6: DISCUSSION

The result shows that the Ernakulam and Ludhiana have conventional Urban Heat Island (the urban LSTs were higher than rural LSTs). However, in cities Tirupur and Bangalore the urban LSTs were lower compared to rural LSTs resulting in the formation of Urban Cool Island (UCI). The LULC, and specifically vegetation in the rural areas seem to be influencing this variation. As in cities Ernakulam and Ludhiana the rural areas are cover by green vegetation, while in cities Tirupur and Bangalore the rural areas are either sparsely covered by Non-Photosynthetic Vegetation (dry grass and shrubs) or barren.

The green vegetation losses the absorbed energy through the process of photosynthesis (evapo-transpiration) thereby results in lower LSTs, but the Non-Photosynthetic Vegetation (NPV) on the other hand doesn’t have chlorophyll to carryout photosynthesis hence cannot perform evapo-transpiration which results in higher LSTs.

Also, the thermal properties of the dry soil (thermal admittance, thermal diffusivity, heat capacity) which are predominantly found in rural areas of the cities Tirupur and Bangalore increases the LSTs of rural surroundings, thereby resulting in Urban Cool Island.

Through this study, we have also found out there is some correlation between LST and NDVI in the cities where Urban Heat Island (UHI) is observed. However, the cities which shows Urban Cool Island (UCI) effect don’t show any correlation between LST and NDVI. This is because of the presence of Non-Photosynthetic Vegetation (NPV) in the rural areas of those cities, which increases the value of NDVI but does not decrease the LSTs in those regions due to the above-mentioned reasons. Thus, the NDVI is not appropriate for quantifying the impact of the urban built-up environment (human-made) on LST across Indian cities.

On the other hand, the NDMI values which gives us the moisture level of different landcover types correlates exactly with the their LSTs for all the study areas irrespective of their location (i.e., if NDMI value increases, the LST decreases and vice versa).

# CHAPTER-7: CONCLUSION

Through the analysis and interpretation of various thematic maps such as LULC, LST, NDVI and NDMI and correlation among them we can say that the Urban Heat Island (UHI) effect is not common for all the cities throughout India. The UHI is determined by the thermal properties of natural and man-made landcover types which in turn are controlled by various factors such as climate, type of vegetation cover, irrigation system, cropping pattern.

The important findings of this study are listed below;

- The study areas where the rural area is covered by green vegetation (Ernakulam and Ludhiana) shows Urban Heat Island (UHI) i.e., the temperature of urban area is higher than that of the rural surroundings.
- The study areas where the rural part is barren or sparsely vegetated (Tirupur and Bangalore) shows Urban Cool Island (UCI) i.e., the temperature of urban area is lower than that of rural counterpart.
- The vegetation type of the rural area is playing a major role in the formation of Urban Heat Island or Urban Cool Island in the cities. These vegetation types are in turn determined by various factors like climate, irrigation pattern, etc.
- The Normalized Difference Vegetation Index (NDVI) which is commonly used for UHI studies is not useful in Indian context as they aren't suitable for differentiating landcover types effectively.
- The thermal properties of the soil are also affecting the Heat Island or Cool Island formation.

From the above result we can conclude that the conventional Urban Heat Island formation is not common to the cities of India. This is due to the fact that rural areas in India aren't like those of North America or Europe from where the UHI research originated. In North America and Europe, the rural area is predominantly covered by greenery (forest and shrubs), which will be cooler than the urban centre. Whereas the rural areas of India are mostly agricultural land which remain barren due to various reasons such as lack of water resource, non-availability of labour, laws, etc. Hence more India centric UHI studies has to be conducted to understand the thermal dynamics of urban and rural areas in India.

# LIST OF FIGURES & TABLES

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