Spatial and temporal structure of urban heat island in Ludhiana city

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Abstract. Since the late 19th century, global warming as obtained more attention as the global mean surface temperature has increased and urbanization is one of the major causes of global warming. Given the fact of the heavy migration of people from rural to urban, uncontrollable growth takes place to accommodate this population. This is considered to be a major problem in developing countries. Ludhiana a city in the state of Punjab, India is considered for the study. In this study, LANDSAT 8 (2019) and LANDSAT 5 (2000 and 2009) were taken from USGS to retrieve Land Surface Temperature (LST) and Land Use Land Cover (LULC). Rapid urbanization resulted in the formation of Urban Heat Island (UHI). The UHI had a mixed pattern of temperature variation for barren, urban, water and vegetation lands. The results of the land covers were computed as normalized indices as Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Normalized Difference Built-up Index (NDBI) and Normalized Difference Barren Index (NDBaI). The relationship between temperature and indices were determined, the NDBI and Normalized NDBaI produced an increase in LST as the range of NDBI and NDBaI increased.

1. Introduction

The economic development has played a vital role in the growth of the country and the living standards of the people. But many countries do not consider the environmental aspect, especially in developing countries. The major problem in a developing country is urban sprawl, due to the uncontrollable growth of the urban areas, it leads to environmental damages. To accommodate the increasing population, land-use change from rural to urban and encroachment of water bodies results in severe environmental damages. The LULC changes in Cities had to be done due to the heavy increase in the population [1]. Hence LULC pattern over the decade is to be taken to find the change in land use [2].
Due to the increasing sprawl, there are changes in the environment. The human activities are not just developing infrastructure, simultaneously exploiting the nature. Over time the changes occur it’s been found that the surface temperature of the region is increased concerning different land cover surfaces. The urban region is always warmer than the surrounding rural region due to anthropogenic activities. This phenomenal difference between the rural and urban temperatures is called urban heat island. The intensity of UHI between day and night varies, it is found that UHI is more during the day and is reduced during winding and cloudy days [3]. The land usage influences the urban temperature during day and night; with proper planning urban heat island can be mitigated [4]. Different land use produces different LST and the building surface is found to be the major contributor to LST [5]. The trends of temperature changes between weekend and weekdays, the UHI is higher during weekdays due to high human activities [6]. Over the decades UHI is increased due to an increase in urbanization [7]. The seasonal variation of UHI is respectively more in summer compared with other seasons. The UHI also has a shifting property within the urban region with the change in season [6, 8]. The reduction of LST is visible with the presence of vegetation [9, 10].

The objective of the study is to determine the spatial spread and intensity of Urban Heat Island (UHI) using Land Surface Temperature (LST) through remotely sensed data, Land Use Land Cover (LULC) pattern of Ludhiana city and also find the relationship between LST and LULC.

2. Data collection

2.1. Study area
Ludhiana is an emerging city in the state of Punjab India, with a total area of extent up to 310 km². The latitude and longitude of the city center are 30.9010° N, 75.8573° E. Ludhiana is the largest city in Punjab and India's largest city to the north of Delhi with an estimated population of 1,618,879 according to the 2011 census. It is centrally located on National Highway 44, which runs from New Delhi to Amritsar and the city stands on the Sutlej River's old banks. For the study purposes, a buffer zone of 12 km radius is considered over the district's Central Business District. It is an industrial center of northern India and called India’s Manchester by UK's BBC.

2.2. Satellite image
The United States Geological Survey (USGS) [9] Public domain in GeoTIFF format which provides geographic maps of the required region from where the images have downloaded the study. The same seasonal period images were chooses over the years and made sure to be clouds free. The table 1 carries the image details chosen for the study. The images were selected from two different satellites LANDSAT 5 and LANDSAT 8 due to technological advancement. The satellite images are a combination of compiling different bands.

3. Methodology

3.1. Detection of LULC
The images are layer stacked; further, it is enhanced and improved for a better pixel quality. The improved image is then clipped for the required study area of Ludhiana. False true colors were produced by combing the bands as per the corresponding satellite is given in the image details Table1. The classifications of the images were done for three years to find the spatial changes concerning time over the year 2000, 2009 and...
Table 1. Ludhiana image details.

| Year | Month | Path, row | Satellite | Band combination |
|------|-------|-----------|-----------|------------------|
| 2000 | March | 148, 39   | LANDSAT 5 | 4,3,2             |
| 2009 | March | 148, 39 and 148, 38 | LANDSAT 5 | 4,3,2             |
| 2019 | March | 148, 39   | LANDSAT 8 | 5,4,3             |

2019[11]. The different land cover of the study area was classified into five categories as urban, water, vegetation, agriculture and barren land, the change in the LULC over the years is detected.

3.2. Retrieval of LST
The skin temperature of the earth’s surface is known as Land Surface Temperature (LST). The LST of the study area is calculated from the thermal band of the satellite image which is band 6 for LANDSAT 5, and band 10 for LANDSAT 8. The thermal bands are further geo-referenced, clipped with shapefile and taken a buffer of 12 Km. The raster calculator in a spatial analysis tool is used to execute the equation for extracting LST. All the details of the image are given in the metadata with the satellite image.

The digital number value [10] of band 10 for LANDSAT 8 and band 6 for LANDSAT 5 is converted into spectral radiant temperature using the following equation. Equations 1 and 2 are common for both LANDSAT 8 and LANDSAT 5, assuming [7] that emissivity is equal to 1 for LANDSAT 5.

\[
L_\lambda = \frac{(L_{\text{max}} - L_{\text{min}})}{(Q_{\text{cal max}} - Q_{\text{cal min}})} + L_{\text{min}}
\]

Where \( L_{\text{max}} \) is the maximum value of radiance of thermal band, \( L_{\text{min}} \) is the Minimum value of radiance of thermal band, \( Q_{\text{cal max}} \) is the Maximum value of quantize calibration of the thermal band, \( Q_{\text{cal min}} \) is Minimum value of quantize calibration of the thermal band.

Further, the spectral radiance extracted from the previous equation is converted to brightness temperature using the following equation.

\[
BT = \frac{K_2}{\ln \left( \frac{L_{\lambda b}}{L_{\lambda h}} \right) + 1} - 273.15
\]

Where \( K_1 \) and \( K_2 \) are Band – specific thermal conversion constant from the metadata, \( L_{\lambda b} \) = radiance temperature, the result obtain in Fahrenheit is converted to Celsius (approx. -273.15°C).

\[
NDVI = \frac{\text{Float (Band 5 - Band 4)}}{\text{Float (Band 5 + Band 4)}}
\]

The calculation of the NDVI is important as the proportion of vegetation (\( P_v \)) is highly related to the NDVI, and emissivity (\( \varepsilon \)), which is related to the P\(_v\), must be calculated.

\[
P_v = \left[ \frac{(NDVI - NDVI_{\text{min}})}{(NDVI_{\text{max}} - NDVI_{\text{min}})} \right]^2
\]

\[
\varepsilon = 0.004 \times P_v + 0.986
\]
Table 2. LULC of classes in Km².

| Year | Water | Urban | Vegetation | Barren | Total |
|------|-------|-------|------------|--------|-------|
| 2000 | 10    | 96    | 534        | 65     | 705   |
| 2009 | 4     | 121   | 502        | 79     | 706   |
| 2019 | 4     | 149   | 483        | 70     | 706   |

\[
LST = \frac{BT}{1 + \left( \frac{0.00115 \times \frac{BT}{L_4388}}{1.4388} \right) \times \ln(e)}
\]  

To obtain the surface temperature map the LST equation (6) is used.

3.3. Derivation of NDVI, NDBI, NDWI, and NDBal

The NDVI, NDWI [5, 12, 13], NDBI, and NDBal indices were used to characterize the LULC type in the study region and to study the relationships between the LULC type and UHI. The density of vegetation is expressed in terms of NDVI which is the Normalized Difference Vegetation Index, using the equations (6) for LANDSAT 8 and equation (7) for LANDSAT 5 as follows.

\[
NDVI = \frac{(\text{band 5} - \text{band 4})}{(\text{band 5} + \text{band 4})}
\]
5

\[ NDVI = \frac{(band~4 - band~3)}{(band~4 + band~3)} \]  

(8)

The density of building is expressed in terms of NDBI [13] which is Normalized Difference Built-up Index, using the equations (8) for LANDSAT 8 and equation (9) for LANDSAT 5 as follows

\[ NDBI = \frac{(band~6 - band~5)}{(band~6 + band~5)} \]  

(9)

\[ NDBI = \frac{(band~5 - band~4)}{(band~5 + band~4)} \]  

(10)

NDWI, Normalized Difference Water Index [12, 14, 15, and 16] gives the density of water in the study area by combining the band's short wavelength infrared and near-infrared, using the equation (10) for LANDSAT 8 and equation (11) for LANDSAT 5 given as follows

\[ NDWI = \frac{(band~5 - band~6)}{(band~5 + band~6)} \]  

(10)

\[ NDWI = \frac{(band~4 - band~5)}{(band~4 + band~5)} \]  

(11)

The barren land density is denoted by NDBal [17] which is the normalized difference barren index, it is found by combing the bands with short wavelength infrared and thermal infrared bands, using the equation (12) for LANDSAT 8 and equation (13) for LANDSAT 5 given as follows

\[ NDBal = \frac{(band~6 - band~10)}{(band~6 + band~10)} \]  

(12)

\[ NDBal = \frac{(band~5 - band~6)}{(band~5 + band~6)} \]  

(13)

4. Result and discussion

4.1. Land use pattern in Ludhiana

Figures 2, 3 and 4 show the different patterns of land cover over the years in the city of Ludhiana. In the year 2000, the urban land is denser at the center of the city, the urban fringe zone is partially filled with urban and agriculture landforms. Comparing Figures 2 and 3 of the year 2000 and 2009 there is a drastic increase in the urban boundary and also the barren land covers have been spread more visibly as a sign of initiation of development. The water bodies in 2009 seem to be quite reducing over the years especially the Sutlej River had been depleted; an increase in barren land cover can be witnessed. There is about a 6% decline in the water body, 26% expansion in urban land, 6% reduction in vegetation and an increase of 21% of barren land changes have occurred from the computation of 2000 to 2009. The agricultural fields have been left unploughed and uncultivated leading to barren landforms and latter occupied with urban land cover. The growth is radially noticeable around the city.

The regions along the highway of NH1, NH 95, Jodhan – Raikot road and Ludhiana – Rohan road have faced a linear development. In the year 2019, the city seems to be under the emerging development of
urban cover, the barren lands left uncultivated in 2009 have been converted to urban in 2019 and the urban fringes are covered with less barren land comparatively with 2009. It can be seen that the urban land is being dominantly increasing among the other land covers at a rate of 23% leading to a sum of 55% increase from 2000 to 2019. The table 2 shows that there is a decline in other landforms. The southeast of the city can be witnessed for major sprawl as the development has occurred along the highway NH 1. the surrounding towns and villages have remarkably increased as a sign of development.

4.2. LST variation
The LST was calculated for three years as given in Table 1. The images were taken during the March month of the years 2000, 2009 and 2019. In the year 2000, the intensity of UHI is less. The range of hot spots is very minimal compared to other years. It could be said that the city is in the initial stages of the UHI phenomenon.

Figures 5, 6 and 7 show the increasing effect of UHI over the years and tabulated in table 3. In the year 2000, there is a defined difference between urban and vegetation. The urban lands have higher temperature radiant than the rural and few parts of the city seem to be facing a high value of LST. The eastern part of the city is facing a higher temperature increase due to the high density of industries present near Jamalpur Colony and MangliNichhi regions. There seems to be an increase in LST along the roadways such as the Gill road and Ludhiana highway. During the year 2009, it can be seen to have a little higher UHI intensity due to newborn barren lands since barren lands produce higher radiance giving rise to LST values. The industry in Karimpur seems to face a high LST and the newborn barren lands developed along the highway especially in Jodhan – Raikot road visibly produce higher temperature radiant. As the Sutlej River has begun to deplete the river beds have been considered to be barren land and they have also produced a higher value of LST. From the year 2019 is noticeable that the urban lands are defined from the rural, the urban fringes have also been predominantly separated. The vanishing barren lands in the Jodhan-Raikot road due to urbanization have reduced the LST value in those regions. In all three years, places with more vegetation seem to have lesser LST.

Comparing the images of all three years is can be noted that the year 2009 has a significantly higher UHI and has many new emerging hot spots. The uncultivated agriculture lands have turned up to be barren and later covered over buildings in the year 2019, as barren lands have higher radiance, the year 2009 has a higher intensity of UHI. The UHI effect is very well visible as the urban land expands the temperature over the changed land cover has also been increased, which states the UHI phenomenon clearly. In 2019 more hotspots have raised as a sign of development. The intensity of the UHI in the surrounding towns and villages has also increased.

4.3. Relationship between temperature and indices

Four different land use classes such as water, vegetation, urban and barren lands are considered in the study. Each class produces a varying range of temperatures depending upon their reflectance. To find this variation concerning temperature and various indices such as NDVI, NDWI, NDBI, and NDBal. With the help of these indices, the relation between LULC and UHI could be found.

In the years 2000, 2009 and 2019 the figures 8, 9 and 10 shows, the relation between temperature and vegetation, it is known that when the vegetation increases UHI intensity has decreased. It can be said that the temperature and NDVI are inversely proportional to each other.

| Description | LST 2000 | LST 2009 | LST 2019 |
|-------------|----------|----------|----------|
| Maximum     | 25       | 45       | 31       |
| Minimum     | 15       | 25       | 14       |
| Mean        | 18       | 30       | 20       |
| Standard Deviation | 1.27   | 3.32     | 1.83     |
Similarly, NDWI and temperature are inversely proportional to each other. On the other hand in the case of NDBI and temperature, it could be seen that when the built-up area increases the temperature is also increased, which in other words can be said that the temperature and built-up area are directly proportional to each other. The NDBaI is also similar to NDBI.
Figure 8. Relationships between LULC and LST of 2000.

Figure 9. Relationships between LULC and LST of 2009.
Figure 10. Relationships between LULC and LST of 2019.

5. Conclusion
The place is indeed needed for development to have a comfortable living; the anthropogenic activities must not only consider about infrastructural development but also environmental aspects. The results interoperated delivers the fact that by increasing the vegetation the LST would be reduced. The water resources must be considered precious, the analysis of the study shows a high water depletion which must be considered as an alarming warning to save them since the increase of water land also reduces the LST value which could be illustrated from the study. The contribution of UHI to global warming would also be reduced as a result. The urban planners and the corporation must pay attention to this as it may serve the future generation.

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