

**QUANTIFICATION OF URBAN HEAT INTENSITY WITH LAND
USE/LAND COVER CHANGES USING LANDSAT SATELLITE DATA
OVER URBAN LANDSCAPES**

6.1 INTRODUCTION

In the recent past few decades, urbanisation has increased as a consequence of rapid population growth which led to adverse effect on our environment. According to the population statistics provided by the United States, urban areas accommodate more than half of global population and also predicted the increase in this ratio in future (United Nations, 2015). People's migration from rural to urban areas is the major cause for urbanisation or growth in the urban sprawl at a large extent due to the increased human activity in the cities. This accounts for the LULC shift from natural land to impervious surface, transportation, industry modifies the thermal conduction with the environment. The impervious land like buildings, roads etc. have higher thermal capacity which captures heat during day and releases during night time. Consequently, higher temperatures in urban areas are detected as compared to the rural areas which can be named as the SUHI. Thus, urbanisation has a direct impact on the LST in an urban area.

Rao (1972) first mentioned about the SUHI effect using satellite remote-sensing. Thermal remote-sensing data have been used for SUHI or LST studies obtained from various satellite-sensors. Various previous studies have demonstrated the significance of TIR data due to its accessibility at different spatial and temporal resolutions (Aniello et al. 1995; Streutker, 2003; Voogt and Oke, 2003; Chen et al. 2006; Tran et al. 2006; Tiangco et al.

2008; Zhang et al. 2010). SUHI intensity depends on various factors like difference in LULC composition in urban and rural areas, thermal conductivities of urban surface, vegetation coverage within a city, anthropogenic discharge from human activities and built-up density (Taha, 1997; Sarrat et al. 2006; Mathew et al. 2016, Zhang and Wang, 2008).

Mathew et al. 2018 proposed a thermal transect method to analyse the seasonal and temporal variations in SUHI from 2003 to 2015 using MODIS thermal data in Jaipur city and found that area enclosed in each isothermal line increased from 20 to 400% indicating significant SUHI growth in 12 years. Zhang and Wang (2008) discussed the spatial extent of SUHI using the relation of HIA with various urban characteristic in ten different cities located at same latitude and found good correlation of HIA with urban size, population density same and development area whereas weak negative correlation with mean NDVI and water proportion was observed. Grigoras and Uritescu (2019) studied the effect of LULC change on SUHI from 1984 to 2016 in Bucharest, Romania using Landsat data. The built-up and fallow land increased whereas green land decreased by 2016 and also difference between the average urban and rural LST decreased representing extension in the area of SUHI. Meng et al. 2018 discussed the spatial and temporal behaviour of SUHI by comparing different levels of SUHI with urban main built-up area for 12 years in Beijing city of China. Li et al. 2018 developed a new method for quantifying SUHI intensity from the relation of LST with ISA using MODIS data. The ISA was regionalised using Kernel density estimation method (KDE) that showed good linear relation with LST and the slope was found effective to quantify SUHI. Keeratikasikorn and Bonafoni (2018) studied the SUHI pattern for different LULC in Bangkok using Landsat 8 data which can help for better land use planning for SUHI mitigation. Sultana and Satyanarayana (2018) studied the LULC change and LST in ten major cities of India from 2001 to 2013 using Landsat data and some ground based measurement. Various cities showed an increase in built-up area by replacing vegetated/bare

land and some cities showed increase in built-up/bare land at the expense of agricultural land and the hotspots increased in the built-up and bare land. Amiri et al. 2009 constructed temperature vegetation index space to study about the LULC change in urban area and its impact on urban LST in Tabriz city of Iran from 1989 to 2001 using Landsat data. Huang et al. 2019 suggested a land contribution index to better quantify the contribution of each LULC on SUHI in Wuhan city of China from using MODIS thermal data. The constructed land contributes greater to the SUHI effect in summer, waterbody shows lowest contribution in spring and urban green spaces has negative contribution towards SUHI effect but was not prominent during winter. The region contributing to strong SUHI increased from 3.35% in 2005 to 8.56% in 2015 of the study area. Shirani-bidabadi et al. 2019 analysed different thermal levels defined from SD to study the influence of urbanisation on the LST from 1999 to 2016 using Landsat 7 ETM+ and Landsat 8 images in Isfahan city of Iran. They proposed an index named heat island ratio observed in the four years (1999, 2006, 2013 and 2016) and SUHI was significant in areas with sparse vegetation, arid land and enhanced industrialisation in the city. Various previous studies discussed the combined effect of bare land and built-ups in SUHI formation. Since urbanisation is a result of replacing bare land or vegetative land cover with built-ups, it is important to study the effect of built-ups on SUHI formation.

The climate change in the urban environment stimulates the study on SUHI which can help in development of strategies to attenuate the negative impacts of SUHI on climate. India is the second most populous country which is the major reason for increasing urbanisation. Therefore, there is an acute requirement to study SUHI growth with urban expansion in Indian cities. Therefore, a new index named Urban Heat Intensity Ratio Index (UHIRI) was proposed in the present study to quantify the urban heat intensity from 1989 to 2018 in Varanasi city of India using Landsat satellite images. Further, contribution of each land cover towards raising or lowering of LST was determined using Land cover contribution index

(LCCI) for years 1989, 1997, 2008 and 2018 to analyse the variation in contribution of each land cover toward LST with change in LULC or urbanisation.

6.2 STUDY AREA AND DATA USED

6.2.1 Study area

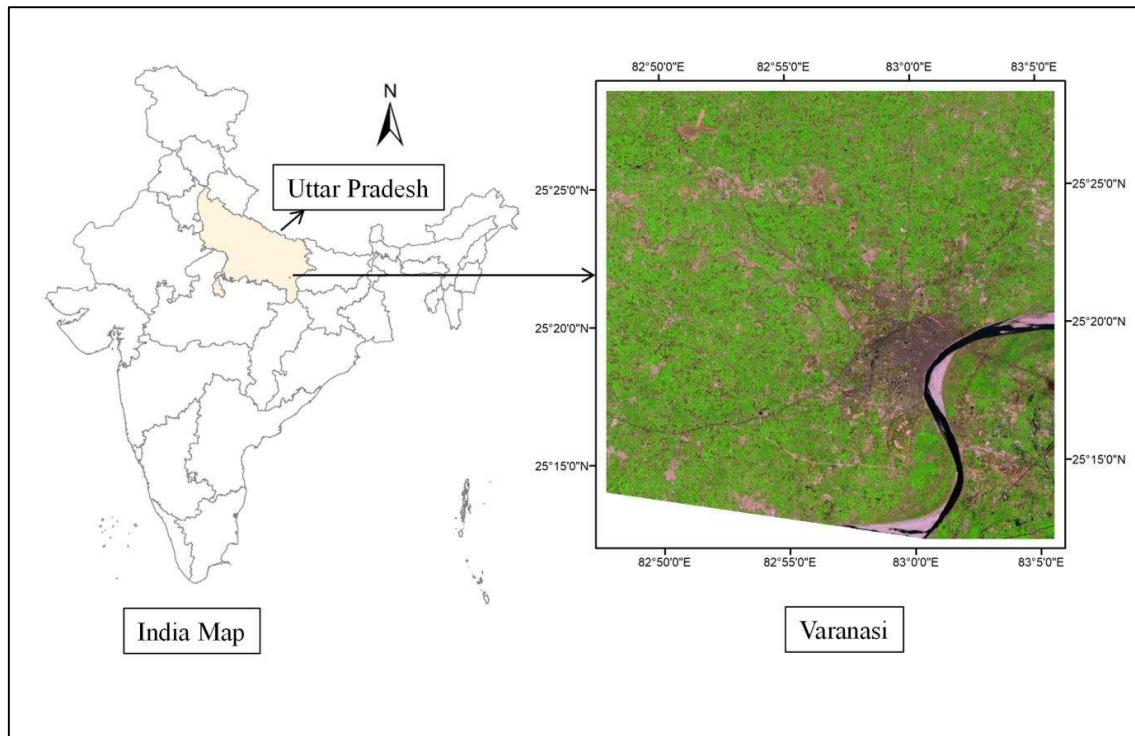


Figure 6.1. Location map of the study area

This study was performed on Varanasi city located in Indo-Gangetic plains of north India also named as Kashi with centre coordinates of $25^{\circ}19'18.06''$ N and $82^{\circ}59'14.24''$ E . This is considered as a holy city and one of the oldest human settlements in the world with population of almost 12 lakhs according to the Census 2011 of India. The city experiences a humid subtropical climate. Varanasi is situated between two rivers i.e. River Varuna and River Ganga enhancing the soil fertility for agriculture purpose. Figure 6.1 shows the location

map of study area. The image is the fcc image of Varanasi, India for year 1989 obtained from Landsat data.

6.2.2 Data used

Landsat satellite data has been made accessible by the USGS since 1972. This provides the longest time series data at a spatial resolution of 30 m which is found most adequate for continuous monitoring of LULC changes due to urbanisation. Landsat 5 TM and Landsat 8 OLI data have been used for the present study from 1989 to 2018 and was downloaded from the USGS website <https://earthexplorer.usgs.gov/>. The data was obtained during clear sky conditions. The specification of the datasets is provided in Table 6.1. The images were clipped according to the defined study area.

Table 6.1 Satellite data specification

Satellite	Acquisition Date	Acquisition Time (UTC)	Path/Row	Cloud cover
Landsat 5 TM	24-02-1989	04:25	142/42	0 %
Landsat 5 TM	14-02-1997	0.4:20	142/42	0 %
Landsat 5 TM	29-02-2008	04:45	142/42	0 %
Landsat 8 OLI	24-02-2018	04:55	142/42	0 %

6.3 METHODOLOGY

6.3.1 Supervised classification and change in LULC

The fcc image was obtained by combining the bands 4-3-2 from Landsat 5 TM data and bands 5-4-3 from Landsat 8 OLI data. The image was classified into four major LULC classes i.e. water, vegetation, bare land and built-ups. The classes were defined by visual interpretation from the spectral signature of each class. Then, Random Forest classification algorithm was applied to obtain the classified image and further, the classification accuracy was assessed. The total number of pixels for each LULC class was determined from each classified image and converted into percentage.

$$\text{Percentage of each LULC class} = \frac{\text{Number of pixels occupied by each class}}{\text{Total number of pixels in a classified image}} \times 100 \quad (6.1)$$

The post-classification method has been used to detect the change in natural land cover (bare land and vegetation) to built-ups from 1989 to 2018 (Singh, 1989). The change maps obtained shows spatial distribution of change in LULC with the evolution over time.

6.3.2 Calculation of normalized LST

LST was calculated using radiative transfer method. The direct comparison of LST of different years may not be appropriate due to the seasonal and inter-annual variability. Therefore, the LST obtained was normalized to make the LST image from different years suitable for comparison.

$$NLST_i = \frac{LST_i - LST_{min}}{LST_{max} - LST_{min}} \quad (6.2)$$

where, $NLST_i$ = Normalized LST of the i^{th} pixel, LST_i = Initial LST of the i^{th} pixel and

LST_{\max} and LST_{\min} = maximum and minimum LST value of the reference LST image

6.3.3 Calculation of Urban Heat Intensity Ratio Index (UHIRI)

A new index was proposed in the present study named as UHIRI to quantify the urban heat intensity for different years. This index determines the effect of built-up areas on LST as compared to the natural land covers present in the study area. Mean normalized LST of natural land covers (T_n) was calculated using Equation (6.3).

$$T_n = \frac{\sum_i T_i \times P_i}{\sum_i P_i}; \quad i = 1,2,3 \quad (6.3)$$

where, $i = 1,2,3$ refers to that of water, bare land and vegetated land respectively, T_i = Normalized LST of i^{th} land cover and P_i = percentage of i^{th} land cover to the total study area. Further, computation of UHIRI was done using Equation (6.4),

$$UHIRI = \frac{T_b - T_n}{T_n} \quad (6.4)$$

where, T_b = mean normalized LST of urban land cover.

6.3.4 Computation of Land Cover Contribution Index (LCCI)

In order to study the contribution of each LULC class on LST, statistics of Normalized LST of each land cover i.e. minimum LST, maximum LST, mean LST and SD on LST for each LULC was determined for four different years. Since, the different LULC types are present in different proportions; the LST statistics cannot describe the contribution of each LULC type on the whole study area. Thus, LCCI was computed which determines the contribution of each LULC type on the entire study area using Equation (6.5). (Huang et al. 2019)

$$LCCI_i = (T_i - T_m) \times P_i ; \quad i = 1,2,3,4 \quad (6.5)$$

where, T_i = mean normalized LST of i^{th} LULC type and T_m = mean LST of the entire study area. Therefore, $LCCI_i$ describes the quantitative contribution of each LULC type on the study area at a particular time period.

6.4 RESULTS AND DISCUSSION

6.4.1 LULC classification and changes

Land cover classifications were carried out in Varanasi region for the years of 1989, 1997, 2008 and 2018 and the images obtained are shown in Figure 6.2.

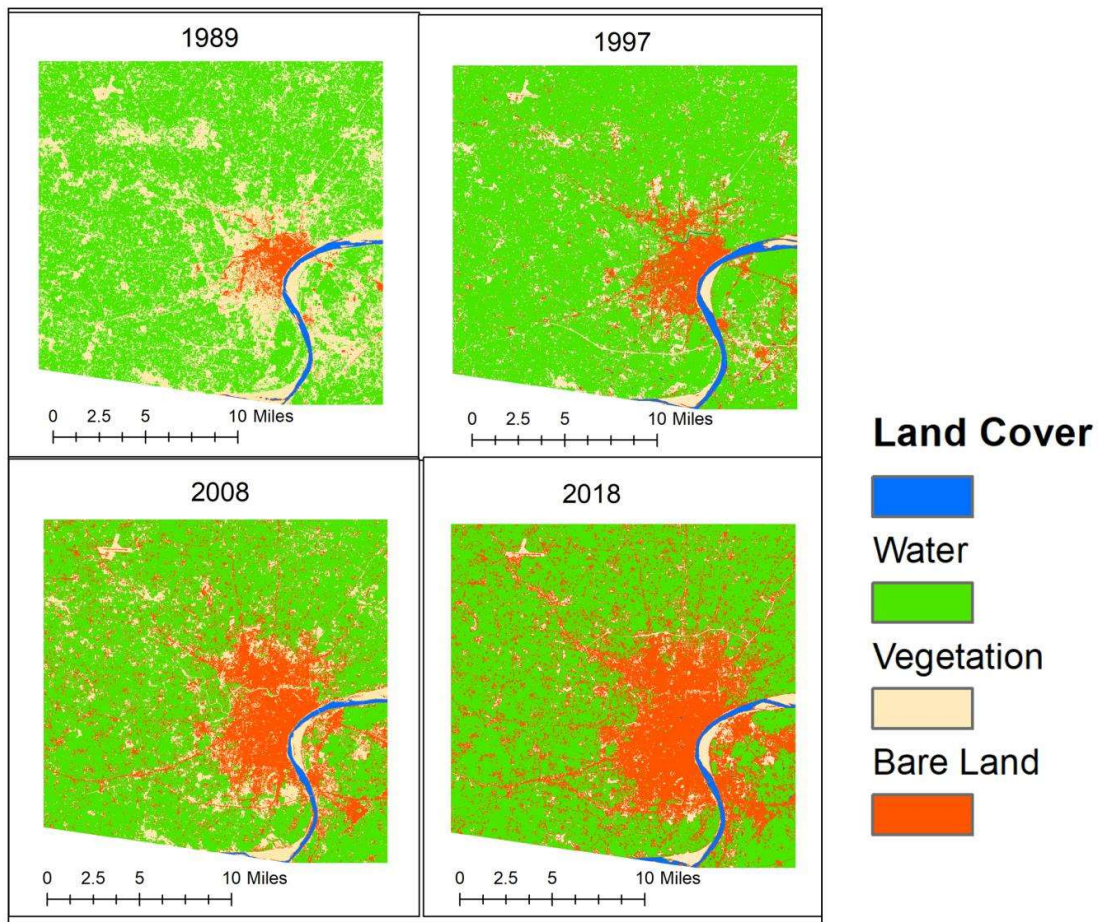


Figure 6.2. Classified map of Varanasi for the years 1989, 1997, 2008 and 2018.

The accuracy assessment of the classification yielded overall accuracy of the classified images to be 95.2% for 1989, 93.7% for 1997, 94.3% for 2008 and 91.5 for 2018. The reasonable high accuracy of the classified images (above 90%) makes it suitable for analysis of urban expansion. The four major land covers were water, vegetation, bare land and built-ups. River Ganga was found to be the major source of water body in the city. The vegetated land covers constitutes mainly the agricultural cropland. The bare land comprises mainly of the fallow land and the dry river bed. Significant rise in the built-up land cover was observed from 1989 to 2018 indicating urban expansion.

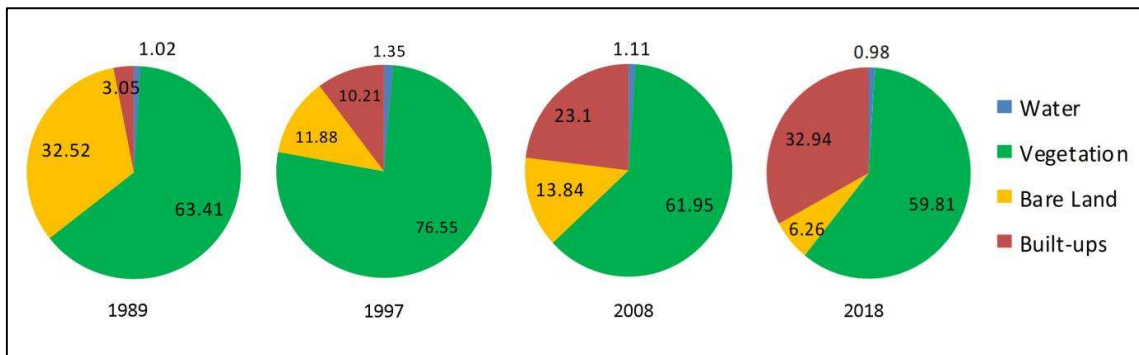


Figure 6.3. Percentage of each LULC type in the years 1989, 1997, 2008 and 2018

Further, percentage of each LULC type to the total land cover (Total area = 866.87 km²) was determined and shown in Figure (6.3). The urban land cover was observed to increase in area by 62.07 km² from 1989 to 1997, 111.74 km² from 1997 to 2008 and 85.30 km² from 2008 to 2018. Therefore, 259.11 km² area of natural land cover was converted into urban built-ups from 1989 to 2018. Vegetation was observed to be the dominant among the natural land cover across the city. In 1989, the vegetation contribution was lower and bare land contribution was higher as compared to that in year 1997. The vegetation contribution was found to decrease from year 1997 to 2018. The urban expansion was the result of replacing bare land or vegetation with the urban built-ups.

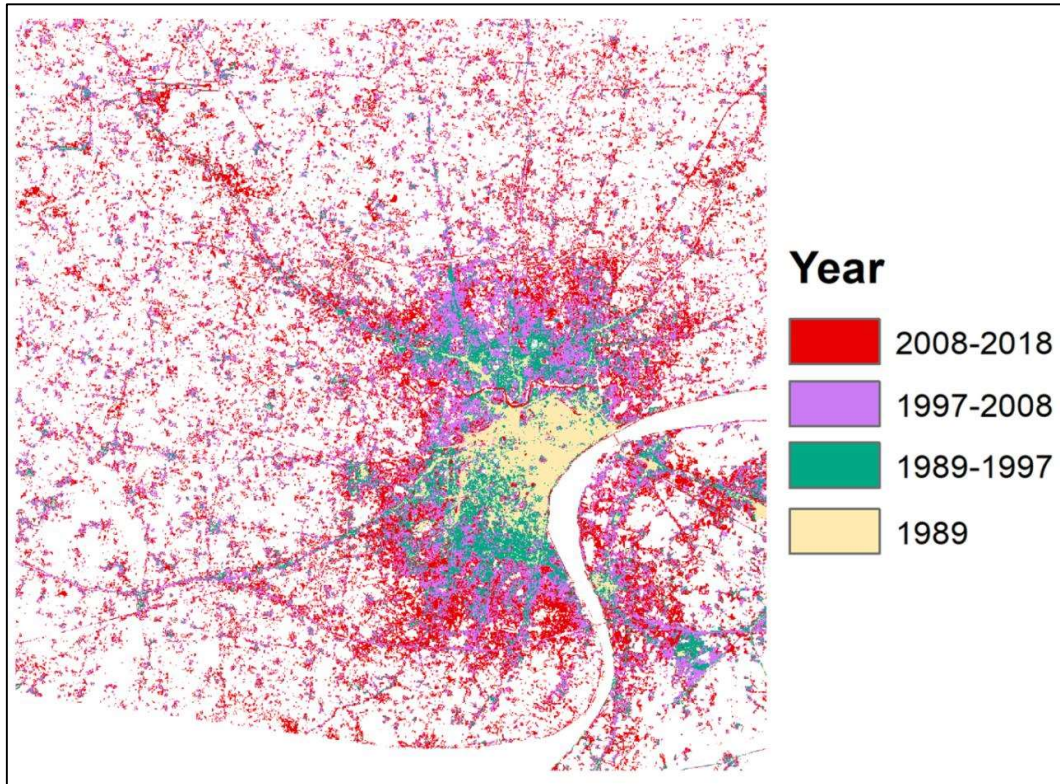


Figure 6.4 Urbanisation mapping from the years 1989 to 2018 of Varanasi city

Urbanisation mapping of Varanasi city from 1989 to 2018, shown in Fig. 4, was obtained from the classified map of Varanasi city. This reveals the areas that have experienced rapid urban growth in 29 years. From 1989 to 1997, urban expansion was observed in the northern and southern region from the centre of the city. Major urban expansion was observed from year 1997 to 2018 in all directions of the Varanasi city. The natural landscapes which are replaced by built-ups have direct influence on the LST of those areas.

6.4.2 Long term Study on LST and quantification of urban heat intensity using UHIRI

Figure 6.5 shows the normalized LST map for the years 1989, 1997, 2008 and 2018. In order to study the LST dependence of each land cover, it is important to understand the thermal signature of each LULC type.

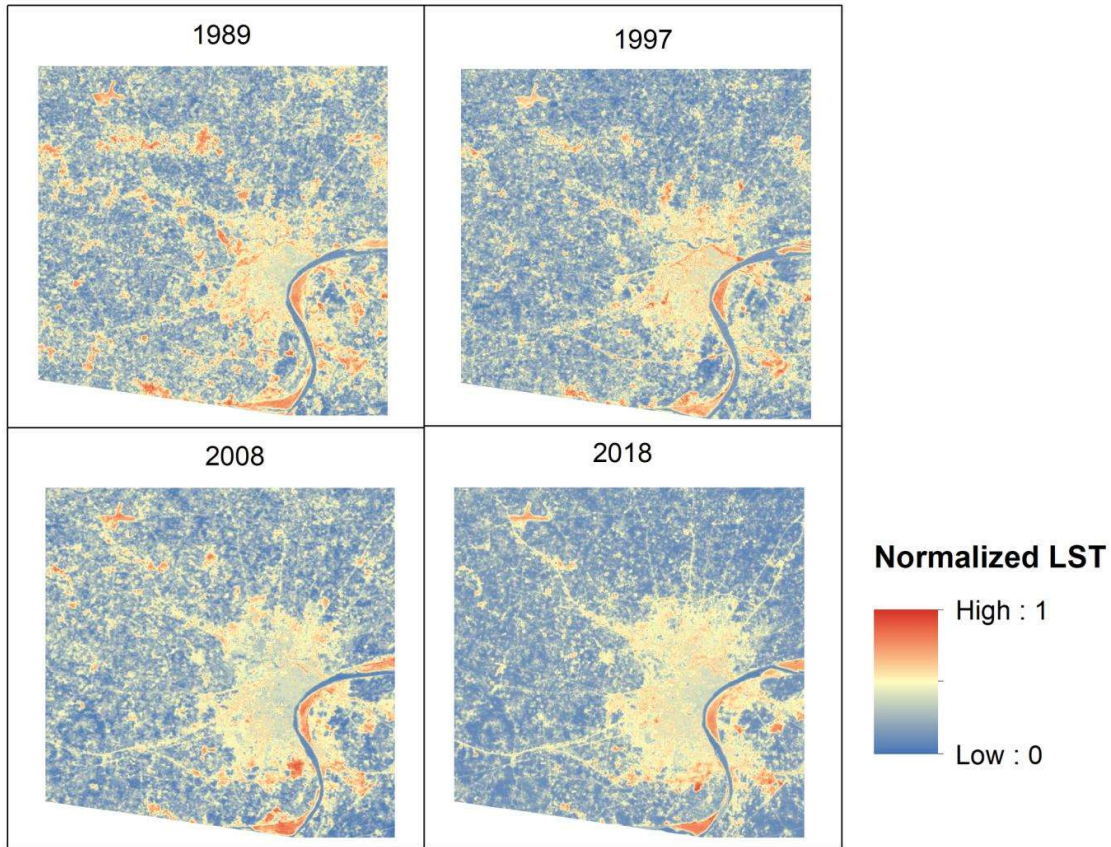


Figure 6.5. Normalized LST map of the years 1989, 1997, 2008 and 2018 of Varanasi city obtained from Landsat images

Varanasi city is surrounded by agricultural region. Thus, the lower LST values surrounding the city were due to the vegetated areas or crops. The river Ganga at the eastern part of the city shows lower LST values whereas the dry river bed results in very high LST as depicted from the four LST images. The high LST pixels across the city represent bare land. Therefore, the waterbody and vegetated land cover shows lower LST values whereas bare land results in higher LST values as compared to the urban land cover. Mean normalized LST of entire study area were determined to be 0.33, 0.30, 0.31 and 0.29 for the years 1989, 1997, 2008 and 2018, respectively. Normalized mean LST of 1989 shows higher value due to presence of more bare pixels. In spite of more urban pixels in 2018, mean normalised LST

show lower value due to presence of less number of bare pixels. The mean LST obtained includes contribution from all the land covers. Since bare pixels have significant influence on the LST, mean normalized LST cannot explain the influence of urbanisation on LST in areas which has combined contribution of vegetation and bare land pixels in rural areas.

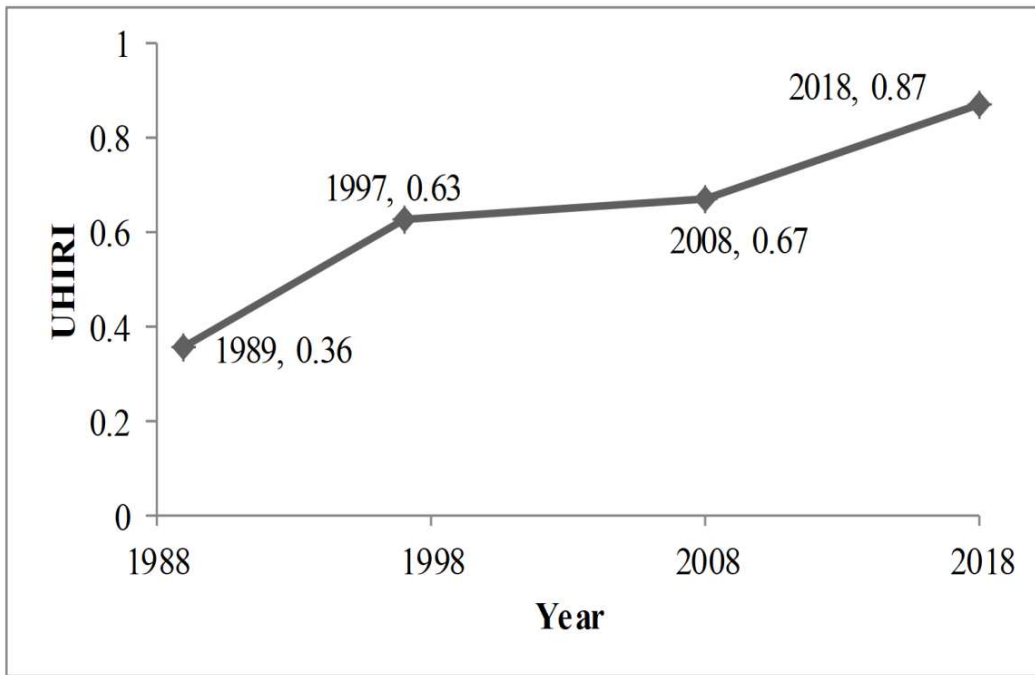


Figure 6.6 Urban heat intensity ratio index (UHIRI) for the years 1989, 1997, 2008 and 2018

In order to determine the effect of urbanisation of LST, a new index was proposed to quantify the urban heat intensity for the data used in the study named as UHIRI. This index was calculated using two major factors i.e. the difference of urban LST with the rural LST and the proportion of urban land in a particular year. Figure 6.6 shows the value of UHIRI for the four years of study which determines the change in SUHI intensity from year 1989 to 2018. The increase in UHIRI value with year clearly indicates the effect of urbanisation on the LST of the city.

6.4.3 LST dependence of each land cover

In order to further study the behaviour of LST with different LULC types, LST statistics of each land cover were obtained for the four different years and plotted as shown in Figure 6.7.

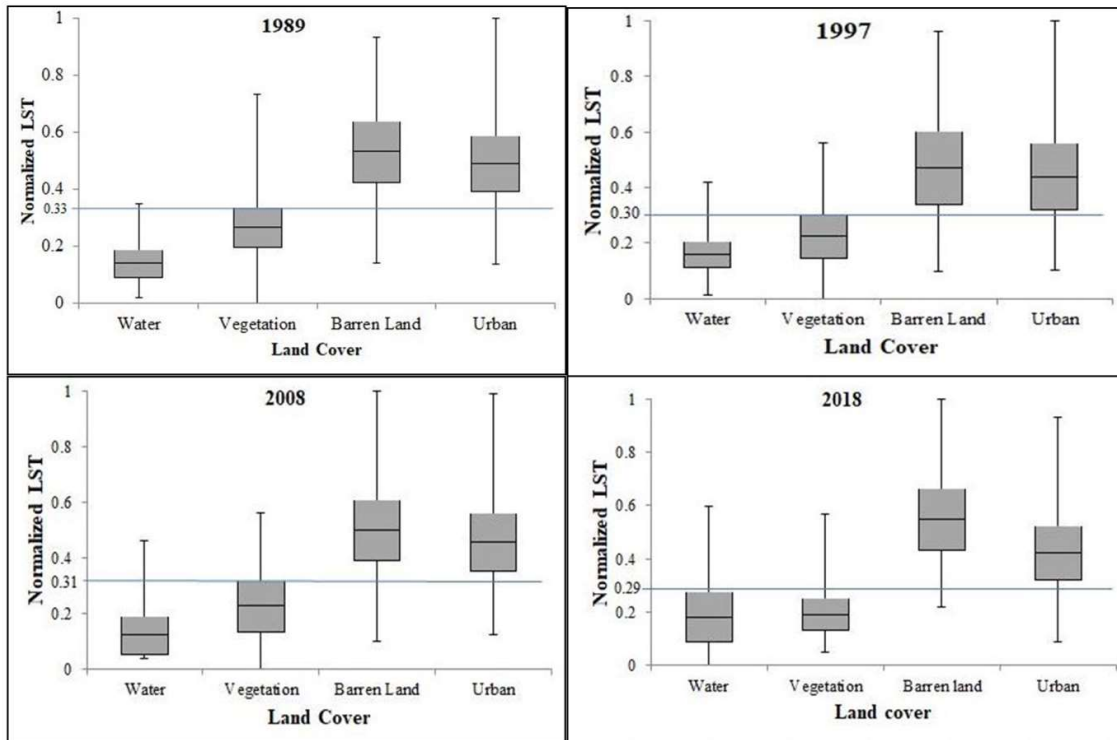


Figure 6.7. Normalized LST statistics of water, vegetation, bare land and urban land covers for years the 1989, 1997, 2008 and 2018

The Figure shows the minimum, mean, SD and maximum LST values for each LULC types and the mean LST of entire area was also shown in the Figure 6.7. Each bar represents the mean \pm SD of normalized LST for each land cover. The horizontal line depicts the mean normalized LST in that year. The higher LST values of bare land and built-ups as compared to the mean LST of entire area depict their positive contribution towards SUHI. On the other hand, the lower LST value of vegetation and waterbody in comparison with the mean LST of

entire area depict their negative contribution towards SUHI as observed in four different years of study. The mean normalized LST and SD for waterbody was found to show lower values as compared to the vegetated land cover in years 1989, 1997 and 2008 whereas both LULC class shows similar mean normalized LST values in 2018 but greater SD was observed for waterbody. Thus, water pixels show lesser contribution towards lowering SUHI in 2018. The SD of bare land and built-ups were found greater than water and vegetation. Soil moisture content of the bare land may vary resulting in greater variation of LST values. The urban built-ups are made up of different materials with varying heat capacity resulting in greater variation in LST values. Thus, the LST statistics determines the contribution of each land cover towards SUHI.

6.4.4 Quantifying the contribution of LULC types on LST

The land cover was observed to change from the year 1989 to 2018 due to urbanisation which has the capability to modify the thermal environment. The area occupied by each land cover was observed to change with time. The contribution of each land cover on SUHI also depends on the proportion of the LULC type present in the region. Thus, the quantification of contribution of each LULC class requires contribution of both LST and the proportion of that LULC class present in the study area. Therefore, LCCI was calculated for each LULC type for the years 1989, 1997, 2008 and 2018 to quantify the contribution of each land cover and are shown in Table 6.2.

Table 6.2 Land Cover Contribution Index (LCCI) for each land covers for the years 1989, 1997, 2008 and 2018

Land cover	1989	1997	2008	2018
Water	-0.19	-0.19	-0.21	-0.11
Vegetation	-3.99	-5.28	-5.23	-5.83
Bare Land	6.57	2.02	2.63	1.63
Urban	0.49	1.43	3.40	4.37

The LULC class with high LST i.e. bare land and built-ups shows positive value of LCCI and those LULC class with low LST i.e. vegetation and waterbody shows negative value of LCCI. The magnitude of the LCCI depicts the quantitative contribution of each LULC type on LST. The LCCI value for built ups from 1989 to 2018 were plotted and shown in Figure 6.8. The significant increase in LCCI values for built-ups indicates quantitative increase in contribution of built-up on SUHI with urban expansion. The LCCI value can distinguish the contribution of bare land and built-ups towards increase in LST which was not possible from the LST statistics. Hence, the LCCI was found useful for quantification of contribution of each LULC type on SUHI.

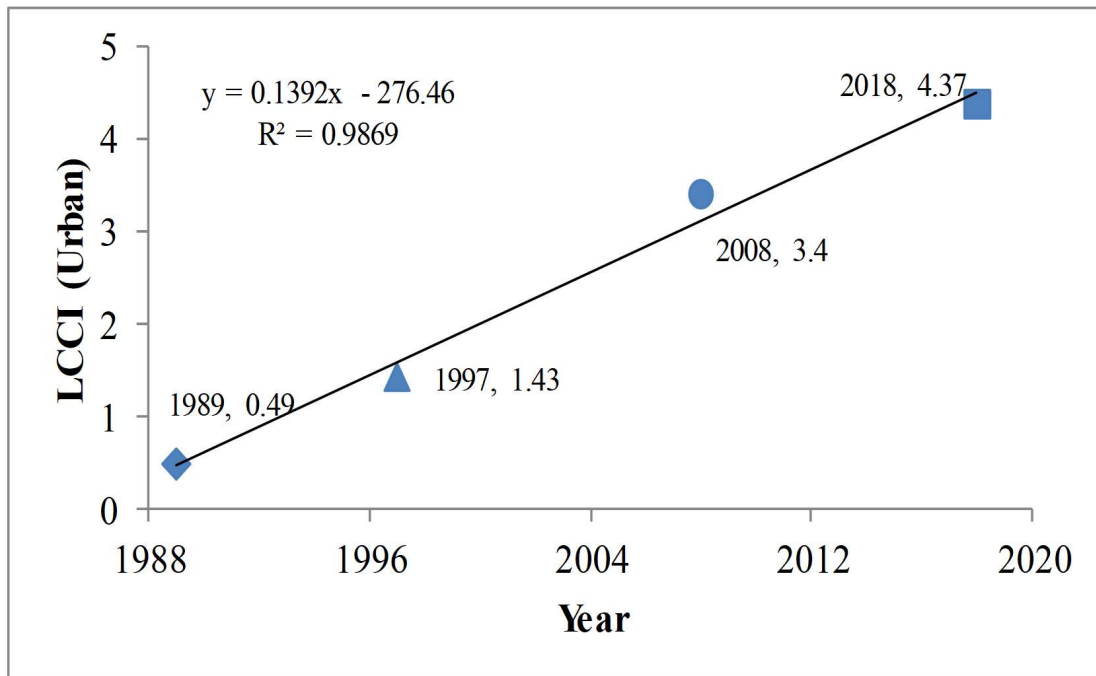


Figure 6.8 Land cover contribution index (LCCI) for urban land cover from 1989 to 2018

The behaviour of UHIRI can also be discussed using the LCCI of each land cover. The LCCI magnitude was found to decrease for bare land and increase for vegetation which resulted in lowering of mean LST of natural land cover. The temperature difference of urban and LST increases and its combination with the increased built-up land cover shows sharp increase in UHIRI value from 1989 to 1997 (0.36 to 0.63). From 1997 to 2008, the slight decrease in vegetation contribution and increase in bare land contribution results in increased mean LST of natural land cover which leads to decrease in the urban and rural temperature difference. By combining this with the increased built-up contribution shows increase in UHIRI value but with a lower magnitude (0.63 to 0.67). Further, the UHIRI value from 2008 to 2018 shows sharp increase due to increased contribution of vegetation and decreased contribution of bare land. The UHIRI value includes both the contribution of temperature difference from built-up and natural land cover as well as proportion of built-up land in the

study areas. Therefore, this index has the potential to explain the effect of urbanisation on LST in areas with greater heterogeneity in LULC types.

6.4.5 LULC change and its effect on LST

Changes in LULC were observed from 1989 to 2018 which has great impact on the LST of the areas within study. It is important to analyse the type of LULC changes that had occurred i.e. natural land cover to other type of natural land cover or natural land cover to urban land cover. The classified maps of 1989 and 2018 were used to determine the pixels where LULC changes had occurred and shown in Figure 6.9. The change map highlights the pixels changed from vegetation or bare land to urban. The bare land and vegetation among the natural land covers that has been replaced by artificial built-up surfaces as a consequence of urbanisation were shown in the change map. Other changes in the map reveal areas where natural land cover was changed by other type of natural land cover which mainly consists of conversion from bare land to vegetation or vegetation to bare land. Therefore, the pixels that have been converted due to urbanisation can be clearly identified from the change map.

It is important to study the impact on LST due to increased urbanisation. The vegetated pixels show lower LST and the bare land pixels show higher LST as compared to the urban pixels. Thus, LST change from bare land to urban and vegetated pixels to urban may show different behaviour. The mean change in normalized LST was calculated for the pixels being converted from bare land to urban and vegetation to urban and plotted as shown in Figure 6.10.

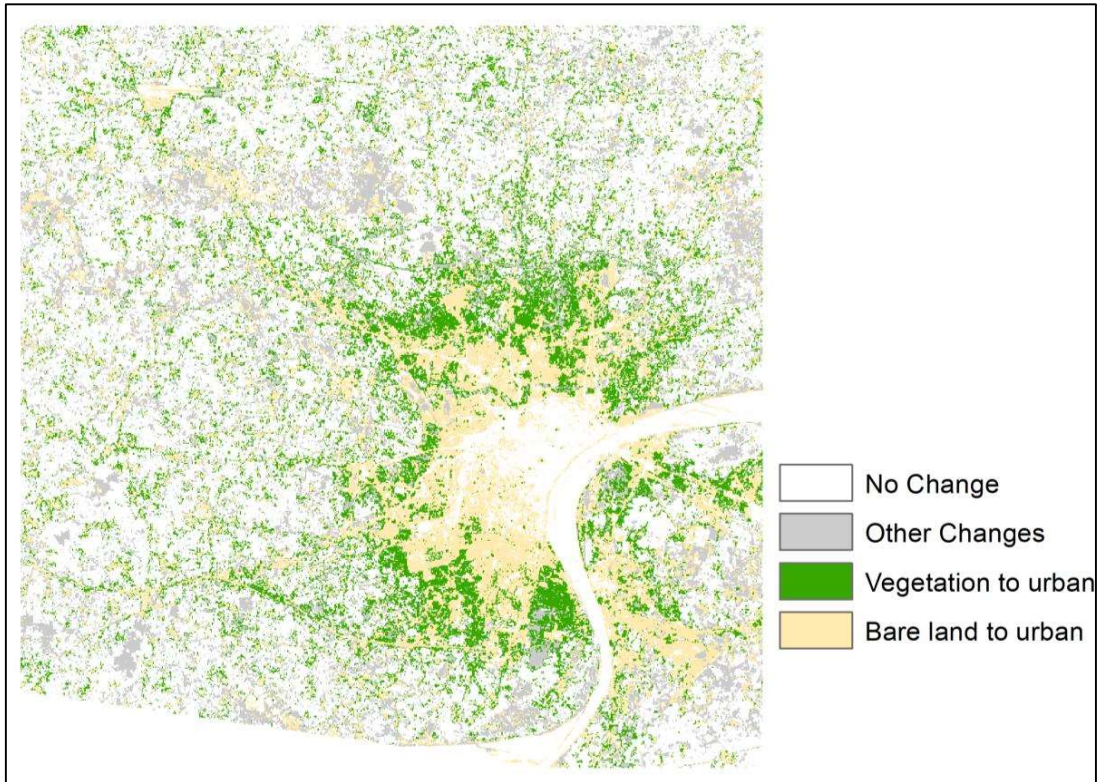


Figure 6.9. Land cover change map for the period 1989 to 2018

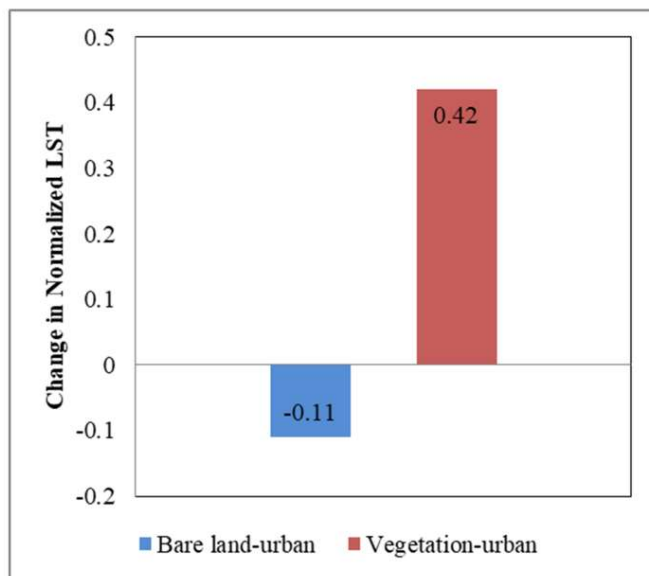


Figure 6.10. Mean difference in normalized LST for pixels converted from bare land, vegetation to urban

Bare land to urban pixels was observed to show negative value with lower magnitude for change in LST which reveals small decrease in LST with this type of urbanisation. Vegetation to urban pixels was observed to show positive value with higher magnitude of change in LST which reveals significant increase in LST. Hence, urbanisation on bare land has very less effect on LST whereas that on vegetated land provides remarkable heating effect. Therefore, replacement of vegetation with urban land cover has severe impact on increasing the intensity of SUHI effect.

6.5 CONCLUSION

In the present study, the effect on LST due to the increase in urbanisation was analysed in Varanasi city of India between years 1989 to 2018 using Landsat satellite images. The classified maps of Varanasi city were obtained for years 1989, 1997, 2008 and 2018 and found that the area of 259.11 km² of natural land cover was converted into urban built-ups between years 1989 to 2018. Thus, a new index named Urban Heat Intensity Ratio Index (UHIRI) was proposed to quantify the urban heat intensity with increasing urbanisation between years 1989 to 2018 in the Varanasi city. UHIRI value was found to increase from 0.36 in the year 1989 to 0.87 in the year 2018 which reveals that urbanisation has significant impact on urban temperatures.

In order to study the behaviour of LST with different LULC types, LST statistics of each land cover were obtained for the four different years i.e. 1989, 1997, 2008 and 2018 and found that the bare land and built-up land covers shows higher LST values as compared to the mean LST of entire area revealing positive contribution towards SUHI. The vegetation and waterbody was found to show lower LST values as compared to the mean LST of entire area depicting their negative contribution towards SUHI. Further, contribution of each land cover towards raising or lowering of LST was determined using Land cover contribution index

(LCCI) for years 1989, 1997, 2008 and 2018 to analyse the variation in contribution of each land cover toward LST with change in LULC. The water and vegetation LULC types were found to show negative value of LCCI whereas the bare land and built-ups showed positive value of LCCI. The LCCI value for urban land cover was found to increase from 0.49 in year 1989 to 4.37 in year 2018 which reveals the significant increase in contribution of urban land cover towards LST. The LCCI value for each land cover was used to understand the behaviour of UHIRI value. The UHIRI value includes both the contribution of temperature difference from built-up and natural land cover as well as proportion of built-up land in the study areas. Hence, this index has the potential to explain the effect of urbanisation on LST in areas with greater heterogeneity in LULC types.

The urbanisation occurs with two types of LULC changes i.e. bare land to built-ups or vegetation to built-ups. The mean difference in normalized LST was calculated for the pixels being converted from bare land to urban and vegetation to urban from years 1989 to 2018. Bare land to urban pixels was observed to show small decrease in normalized LST whereas vegetation to urban pixels showed significant increase in normalized LST. Therefore, replacement of vegetation with urban land cover has severe impact on increasing the intensity of SUHI effect.

Therefore, this analysis discusses about quantification of the SUHI effect with increasing urbanisation and also the contribution of each land cover towards SUHI. Further studies can be performed to study the effect on night LST with changing LULC types and contribution of each land cover on night LST with increasing urbanisation.