Chapter 4

ESTIMATION OF LAND SURFACE TEMPERATURE (LST)

4.1 INTRODUCTION

One of the main objectives of this study is to assess the LST which involves the use of thermal remote satellite data. Accordingly it is necessary to briefly introduce the some very basic/fundamental aspects of physics which involve the understanding of thermal properties of an object and spectral characteristics etc. Land Surface Temperature (LST) is defined as the temperature of the interface between the Earth’s surface and its atmosphere and thus it is a critical variable to understand land-atmosphere interactions and a key parameter in meteorological and hydrological studies, which involve energy fluxes (Niclos et al., 2009).

The thermal infrared TIR region extends from 3.00µm to 12.0µm in the electromagnetic spectrum (EMS). The energy in this wavelength region is essentially the radiation that is emitted (not reflected) from the earth surface (Figure 4.1). Most commonly used are the intervals from 3-5µm (MIR) and 8-12µm (TIR), in which the atmosphere is fairly transparent and the signals are only lightly attenuated by the atmosphere absorption. The energy emitted by a surface is proportional to its temperature. Since thermal remote sensing does not depend on reflected sunlight so, the emitted energy can be observed during the night time also. Approximately 80 percent of the energy thermal sensors receive in the 10.5-12.5µm wavelength region is emitted by land surface, making surface temperature the easiest variable to extract from the thermal infrared signal (Quattrochi and Luvall, 2004). The remaining 20 percent is
emitted by the atmospheric aerosols and other spurious noises from certain bodies’ midway.

![Window structure of the atmosphere](http://coldregionsresearch.tpub.com/rsmnl/rsmnl0027.htm)

Figure 4.1: Window structure of the atmosphere (x axis) wavelength; (y axis) atmospheric transmittance

A black body is the concept, which is widely used by physicists in the study of radiation. A black body is a hypothetical, ideal radiator that totally absorbs and reemits all energy incidents upon it. If an object is a blackbody, it behaves exactly as the theoretical laws predicts. True blackbodies do not exist in nature, although some materials (e.g. clean, deep water between 8-12\(\mu\)m) can be very close to it. So, for a given temperature and wavelength, no surface can emit more energy than a black body. All bodies are not perfect black bodies rather they act as grey bodies.

### 4.2 METHODOLOGY FOR DERIVING LST

Figure 4.2 shows the flow diagram of methodology for the estimation of LST for different time periods i.e., 2000 and 2011 for three different months. For deriving LST LANDSAT-7 ETM+ thermal channel (10.4-12.5\(\mu\)m) (Band 6) and LANDSAT-5 TM thermal channel (10.4-12.5\(\mu\)m) (Band 6) have been used for deriving LST images for 2000 and 2011 respectively.
4.2.1 Retrieval of LST from the LANDSAT-5 TM images

Band 6 was used in the estimation of surface temperature. First, the digital numbers (DNs) of Band 6 are converted to radiance luminance ($R_{TM6}$, mW/cm²·sr⁻¹) using the pre-launch calibration constants (Schott and Volchok, 1985) by the following formula:

$$R_{TM6} = \frac{V}{255} (R_{max} - R_{min}) + R_{min}$$

Equation (i)

where: $V$ represents the DN of Band 6 and

$$R_{max} = 1.896 \text{ (mW/cm}^2\text{·sr}^{-1})$$
\[ R_{\text{min}} = 0.1534 \text{ (mW}^*\text{cm}^{-2}\text{sr}^{-1}) \]

The radiation luminance is converted to at-satellite brightness temperature in Kelvin, \( T(K) \), by the following equation:

\[
T(K) = \frac{K_1}{\ln\left(\frac{K_2}{R_{\text{TM}6/b} + 1}\right)} \quad \text{Equation (ii)}
\]

Where, \( K_1 = 607.66 \text{ (mW}^*\text{cm}^{-2}\text{sr}^{-1}\mu\text{m}^{-1}) \) and \( K_2 = 1260.56 \text{ (Kelvin)} \), where are pre-launch calibration constants: \( b \) represents effective spectral range, when the sensor’s response is much more than 50\%, \( b = 1.239 \text{ (\mu m)} \).

Further Kelvin images \( T(K) \) converted to Degree Celsius images (\(^\circ\text{C}\)), by the following equation:

\[
\text{Degree Celsius (}\ ^\circ\text{C}) = (T(K) - 273) \quad \text{Equation (iii)}
\]

4.2.2 Retrieval of LST from the LANDSAT-7 ETM+ images

The LANDSAT-7 ETM+ 1G products were utilized for retrieving temperature in 2000. The approach to the retrieval of temperature was described in the LANDSAT-7 User’s handbook. It is also simplified to two separate steps as follows:

First, the DN\( s \) of bands were converted to radiance by the following formula:

\[
\text{Radiance} = \text{gain} \times \text{DN} + \text{offset};
\]

This can also be expressed as:

\[
\text{Radiance} = (L_{\text{MAX}} - L_{\text{MIN}})(Q_{\text{CALMAX}} - Q_{\text{CALMIN}}) \times (Q_{\text{CAL}} - Q_{\text{CALMIN}}) + L_{\text{MIN}} \quad \text{Equation (iv)}
\]

The gain and offset can be obtained from the header file of the images, \( Q_{\text{CALMIN}} = 1, Q_{\text{CALMAX}} = 255, Q_{\text{CAL}} = \text{DN} \), and \( L_{\text{MAX}} \) and \( L_{\text{MIN}} \) (also
given in the header file of the images) are the spectral radiances for band 6 at digital numbers 1 and 255 (i.e., QCALMIN and QCALMAX), respectively.

Then the effective at-satellite temperature of the viewed atmosphere system under the assumption of a uniform emissivity could be obtained from the above spectral radiance by the following equation:

$$T(K) = \frac{K2}{\ln\left(\frac{K1}{L_{\lambda}} + 1\right)}$$

Equation (v)

Where, $T$ is effective at-satellite brightness temperature in Kelvin; $K1=666.09$ (mW/cm$^2$/sr/µm$^{-1}$) and $K2=1282.71$(Kelvin) are calibration constants; and $L_{\lambda}$ is the spectral radiance (mW/cm$^2$/sr/µm$^{-1}$)

Table 4.1: Thermal band calibration constants

<table>
<thead>
<tr>
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<th>LANDSAT-5 TM</th>
<th>LANDSAT-7 ETM+</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1 (mW$^{-2}$/sr$^{-1}$/µm$^{-1}$)</td>
<td>607.76</td>
<td>666.09</td>
</tr>
<tr>
<td>K2 (Kelvin)</td>
<td>1260.56</td>
<td>1282.71</td>
</tr>
</tbody>
</table>

(Source: LANDSAT 5 TM & LANDSAT-7 ETM+ user handbook)

Further, Kelvin images $T(K)$ converted to Degree Celsius images ($^\circ$C), by the following equation:

$$Degree\ Celsius\ (^\circ C) = (T(K) - 273)$$

Equation (vi)

4.3 LST ESTIMATION FOR 2000

4.3.1. Ward-wise analysis of LST in March 2000

Figure 4.3 (a) shows the spatial distribution of LST 05th March 2000 (Day time) at 10:48 hrs. (local time). The estimated LST ranges from 17.63$^\circ$C to 41.31$^\circ$C with a mean value 31.04$^\circ$C and standard deviation 03.18$^\circ$C. It is observed that east, south-east and some part in north of Jaipur city exhibits the highest temperature (above 40$^\circ$C) mainly due to the presence of bare soil. Some of the high temperature zones are also seen around the V. K. I. industrial area.
Assessment of Impact of Urbanization on Micro-Climate in Jaipur Urban Complex based on Satellite Derived Parameters

(north) and to its south-west which predominately contain much bare soil and agriculture fallow land. These areas experience even higher temperature than that of high dense built-up area. In the northern part of the Jaipur city particularly Machra, Mahapura, Kisanbagh areas are having relatively high temperature. Towards the southern and south-western part of Jaipur city, International airport and Sanganer also record relatively higher temperature mainly due to predominance of concrete and bare/scrub soil in nearby areas. The moderate level of LST (37°C to 40°C) is observed in core part of the city, eastern Jaipur and southern part of the city. Outer part of the main city has observed low surface temperature due to agriculture land, vegetation and less settlement (Gokulpura, Kohnakpura and Sirsi etc). A linear pattern of low surface temperature is observed on hills.

Figure 4.3 (b) shows the ward wise distribution of mean LST. The ranges of ward wise mean LST in this season was recorded as 29.70°C to 34.37°C. The wards in the south-eastern and eastern part of the JMC have maximum mean LST mainly due to presence of agriculture fallow land and bare soil. Some pockets of high temperature exist in the central part of the city. Low temperature was observed in south-western and north-eastern part of the city.

Highest mean LST (Figure 4.4) is recorded in ward no. 48 (Jamdoli) with 34.37°C, ward no. 69 (Vidyadhar Nagar/V. K. Industrial) with 34.16°C, ward no. 07 (Khatipura) with 33.99°C and ward no. 27 (Jhalana Dungri) with 33.71°C. Ward no. 52(Badanpura) with 29.70°C found low mean temperature due to the very dense vegetation and water body (Mansagar Lake). Ward no.12 (Maniyawas) with 29.74°C and ward no. 02 (Hathod) with 30.23°C recorded relatively low temperature which may be explained as being due to dominant agriculture cropland land cover. (Detailed statistics of ward wise mean LST has been enclosed as Appendix 4).
Figure 4.3: (a) Spatial distribution of LST (b) Ward wise distribution of mean LST(March 2000)
4.3.2. Ward wise analysis of LST in May 2000

The temperatures ascend sharply in summers and the pattern of spatial distribution of temperature transform significantly. Figure 4.5 (a) shows the spatial distribution of LST, dated 24th May 2000. The temperature in summers ranges from 28.61°C to about 42.59°C. The water bodies (drains, river and lakes), ridge forests and other forests patches record lower temperatures (upto 28°C).

The eastern, south-western and north-western parts of city, that are mainly the newly built-up and agricultural land, experience relatively highest temperatures (upto 41°C). Areas with high proportion of fallow land also record relatively highest temperature. The open areas of Jaipur international airport also experience intense heating (about 40 °C). It is important to note that areas with highest temperature in summer, experienced lowest temperature in winter, thus observing the highest temperature range as compared to the other areas. Industrial areas correspond to higher LST areas viz. exist in the northern (V.K.I) and southern (Sitapura Industrial) part of the city. The central, southern and eastern parts of Jaipur (mainly built-up land) observe moderate
Figure 4.5: (a) Spatial distribution of LST (b) Ward wise distribution of mean LST (May 2000)
temperature (34°C - 39°C). A linear pattern of moderate surface temperature is also observed along the major road network. Excluding ward no. 69 which is prominently an industrial area thus records higher temperatures > 39°C. Wards located in remaining central part of the city has recorded mean LST in moderate ranges. Low mean LST were observed in few wards which are having water bodies or dense vegetation land cover especially north-east, extremely eastern part of the city.

The spatial distribution of mean LST in different wards has been further analysed to see the contribution of the individual wards and mean LST (Figure 4.5 (b)). It is also represented graphically in Figure 4.6. It is found that the wards in the eastern, south-eastern, western and north-western part of the JMC have maximum mean LST mainly due to large proportion of agriculture fallow land, bare/scrub soil and newly constructed colonies.

Figure 4.6: Wardwise variation in mean LST in JMC area (May 2000)

Figure 4.6 shows that there is an relatively increase in mean LST of some wards with change in season. The highest mean LST has been found in the ward no. 2 (Hathod) with 39.31°C, ward no. 24 (Herapura) with 39.17°C, ward no.3 (Vaishali Nagar) with 39.11°C, ward no. 48 (Jamdoli) with 39.03°C etc. Lowest mean LST were found in the ward no. 30 (Jawahar Nagar) with
36.51°C, ward no. 61 (Purani basti) with 36.69°C and ward no. 52 (Ambedkar colony) with 35.98°C etc. (Detailed statistics of ward wise mean LST has been enclosed as Appendix 5).

4.3.3. Ward wise analysis of LST in October 2000

In autumn of 2000, the temperatures again ascend sharply as compared to summer season. Figure 4.7 (a) shows the spatial distribution of LST, on 15th October 2000. The estimated LST ranges from 23.98°C to 46.20°C (mean value of 42.35°C and standard deviation 2.98°C). October was very hot month in year 2000. Overall high temperatures have been recorded in this season in all parts of the city as compared to May month. However, the spatial patterns of LST are similar to summer season. The bare/scrub land and some parts of agriculture fallow land records relatively high temperatures. Relatively moderate temperatures (32°C- 40°C) occur in high and low dense built-up areas which dominate the central and southern part of the city. Relatively lower temperatures (23.98°C -32°C) are recorded in the northern, north-eastern, central and eastern of the city dominated by water bodies and dense vegetation.

Figure 4.7 (b) shows the ward wise distribution of mean LST. Overall increase in mean LST at ward level as compared to May 2000 is clearly evident in the Figure. Wards in the north, western, south-western and south-eastern part of the city have relatively maximum mean LST mainly due to bare/scrub soil and high/low dense built-up areas. Some wards of high temperature invariably exists in the wards located in south-western and entire western part of the city. Moderate mean LST were observed in peripheral wards of the city. Relatively low temperature occurs in some wards located in central and north-eastern part of the city. Figure 4.8 shows the graphical distribution of mean LST in different wards in October 2000. Highest mean LST have been recorded in the ward no. 23 (Bambala) with 45.01°C, ward no. 69 (V.K.I Area) with 43.05°C, ward no.
Figure 4.7: (a) Spatial distribution of LST (b) Ward wise distribution of mean LST (October 2000)
Assessment of Impact of Urbanization on Micro-climate in Jaipur Urban Complex based on Satellite Derived Parameters

Figure 4.8: Wardwise variation in mean LST in JMC area (October 2000)

03 (Vaishali Nagar) with 43.36°C, and ward no. 65 (Shastri Nagar) with 42.65°C due to industrial/commercial area and high dense built-up area. But ward no. 24 (Herapura) with 45.08°C, ward no. 2 (Hathod) with 44.23°C, and ward no. 12 (Maniyawas) with 43.70°C primarily due to predominance of bare/scrub soil.

Moderate mean LST were found in the wards of ward no. 53 (Devisinghpura) with 40.97°C, ward no. 14 (Durgapura) with 40.96°C, ward no. 13 (Mansarovar) with 40.93°C, ward no. 68 (Bhawani Nagar) with 40.74°C, ward no. 59 (Gangauri Bazar) with 40.69°C, ward no. 21 (Jawahar Nagar) with 40.69°C and ward no. 09 (Shanti Nagar) with 40.66°C. Lowest mean surface temperatures were found in the Chandpol (ward no. 40) with 38.37°C, Badanpura (ward no. 50) with 39.03°C and Subhash Nagar (ward no. 62) with 39.97°C. (Detailed statistics of ward wise mean LST has been enclosed as Appendix 6). Notably, the lower scale of ward level mean LST is higher in October 2000 as compared to earlier two seasons i.e., March and May.
4.4 LST ESTIMATION FOR 2011

4.4.1. Ward wise analysis of LST in February 2011

Figure 4.9 (a) shows the day time surface temperature derived using LANDSAT TM data of 28th February 2011 (spring season) at 10:45hrs. (IST). The study shows that the estimated surface temperature ranges from 20.96°C to 42.02°C (pixel mean level value 25.68°C and standard deviation 1.92°C). During this season, the LST distribution has observed increased as compare to 2000 March month. It is notable that in the end of February, which is not a hot month as per normal cycle of season in the region, southern, western, south-eastern and south-western part of the city records LST high as more than 40°C i.e Jagatpura, Pratap Nagar, Herapura, Ganga Vihar and Maniyawas area were observed highest LST (40°C to 42.02°C) that corresponds to high dense built-up, bare/scrub soil and industrial/commercial areas. Moderate temperatures (35°C to 40°C) occur in the central part of the city. Water bodies and dense vegetation correspond to very low temperature (30°C to 20°C). A linear pattern low LST is observed on hills and on predominantly agricultural cropland area.

Figure 4.9 (b) shows the ward wise mean LST. It is observed that relatively highest temperatures correspond to larger bare/scrub soils. The wards located in area of some southern and south-eastern parts of the city have maximum mean LST mainly due to predominance of bare/scrub soil and built-up area. It is also observed that north and central wards are having moderate temperature ranges. Low temperature was observed in wards located in west and north-east parts of the city. Some wards which have large area covered by water body and dense vegetation are having also relatively low temperatures.
Figure 4.9: (a) Spatial distribution of LST (b) Ward wise distribution of mean LST (February 2011)
Figure 4.10 shows ward wise distribution of mean LST. The uneven distribution of LST across various wards of the city can be explained as being due to mixed land use pattern in Jaipur city.

![Wardwise variation in mean LST in JMC area (February 2011)](image)

Highest temperature is found in the ward no. 24 (Herapura) with 36.12°C, ward no. 28 (Jagatpura and Pratap Nagar) with 35.08°C and ward no. 23 (Bambala) with 35.08°C. Moderate mean surface temperatures were observed in ward no. 22 (Sanganer) with 34.98°C, ward no. 54 (Kagdiwara) with 34.53°C and ward no. 14 (Durgapura) with 33.84°C etc. Lowest temperature were found in the wards of ward no. 29 (Jobner Bagh) with 32.23°C, ward no. 02 (Hathod) with 32.25°C (Detailed statistics of ward wise mean LST has been enclosed as Appendix 7).

4.4.2. Ward wise analysis of LST in May 2011

The temperatures ascend sharply in summers and the pattern of spatial distribution of temperature transforms significantly. Figure 4.11 (a) shows the spatial distribution of LST, on 31st May 2011. The LST ranges from 28.49°C to about 46.87°C (mean value of 41.29°C and standard deviation 1.69°C). Low
Figure 4.11: (a) Spatial distribution of LST (b) Ward wise distribution of mean LST (May 2011)
temperatures (upto 28°C) corresponds to water bodies and dense vegetation cover record low temperatures. The eastern, south-eastern, south-western and whole western part of the city, which are mainly characterised by newly high/low dense built-up, agricultural cropland and scrub/bare soil experience highest temperatures (upto 47°C). The agriculture fallow land and bare soil also experience intense heating (about 44°C). The northern and whole central part of the city have moderate temperatures (34°C to 40°C). Low temperatures were found in north-eastern part of the city.

Figure 4.11 (b) shows the spatial distribution of mean LST in different wards in terms of mean LST. It is also important to note that Jaipur city experience overall increase of 2.63°C in mean LST over 11 years in May. The same has been represented graphically in Figure 4.12. Wards in the eastern, south-eastern and whole western part of the JMC have maximum mean LST mainly due to predominance of agriculture fallow land, high/low dense built up areas and bare/scrub soil. Some pockets of high temperature also exist in the northern part of the city. It has been observed that during day time fallow land exhibits the highest LST. Moderate temperature was observed in all wards located in middle part of the city extending north to south. Only three wards located in central and north-eastern part of the city have recorded low temperature which may be attributed to areas of dense vegetation and water bodies in these wards.
Figure 4.12: Wardwise variation in mean LST in JMC area (May 2011)

Figure 4.12 shows that there has been increase in mean LST of majority wards with change in season. Figure shows a very uneven temperature distribution. The highest mean LST was found in the ward no. 02 (Hathod) with 42.77°C, ward no. 24 (Herapura) with 42.41°C, ward no. 48 (Jamdoli) with 42.19°C, ward no. 28 (Jagatpura and Pratap Nagar) with 41.47°C and ward no. 27 (Jhalana Dungri) with 41.01°C. Notably these of wards have large pockets of newly built up areas, bare/scrub soil and agricultural fallow land.

Relatively low mean LST observed have been in ward no. 52 (Karbala) with 38.64°C, ward no. 40 (Chandpol) with 38.90°C, Ward no. 61 (Berava Basti) with 38.95°C and ward no. 35 (Rambagh) with 39.34°C. These wards have large areas under dense vegetation and sparse vegetation (grass/parks etc) (Detailed statistics of ward wise mean LST has been enclosed as Appendix 8).

4.4.3. Ward wise analysis of LST in October 2011

Figure 4.13 shows the spatial distribution of LST on 22nd October 2011. The estimated LST ranges from 26.28°C to 39.80°C (mean value of 33.92°C and standard deviation 1.9°C). The season was relatively less hot as compared to October, 2000 mainly attributed to heavy rains. In October 2011, western
portions bear elevated temperatures, with the relatively maxima reached in south-west Jaipur. Central and northern part of the Jaipur are relatively cooler, with the exception of a few patches (Figure 4.13 (a)). It is observed that in the north of Jaipur i.e., V. K. I industry which corresponding to industrial/commercial land observed the highest surface temperature, and same thermal zone also observed in the south and south-east Jaipur, contains bare/scrub hotspots of soils it also exhibits the highest temperature (37°C to 39.80°C). Apart from bare soils land use areas some of the relatively high temperature zones are also seen in the northern and central part of the Jaipur, mainly due high/low dense built-up land use, contains much impervious surface.
Figure 4.13: (a) Spatial distribution of LST (b) Ward wise distribution of mean LST (October 2011)
Relatively moderate levels of LST are seen in peripheral part of the walled city, is mainly distributed within the built-up areas, which often contains urban concentrate surface and low vegetation areas. Relatively low temperatures were observed in the wards of central part of the city.

The spatial distribution of mean LST in different wards was further analysed to see the contribution of individual wards and the mean LST in Figure 4.13 (b). It is also found that the wards in the south, south-west and south-east of the JMC have relatively high mean LST mainly due to agriculture fallow land and bare/scrub soils. Moderate temperatures were observed in the north, west, south-west wards of the city. Low LST were observed in central wards of the city with 31°C to 33°C.

![Figure 4.14: Wardwise variation in mean LST in JMC area (October 2011)](image)

The graphical distribution of mean LST in different wards was further analysed to the contribution of individual wards and the mean LST is shows in Figure 4.14. It shows a very uneven temperature distribution which is also quite clear. This is because of mixed land use pattern in Jaipur city. Relatively highest mean LST is found in the ward no. 02 (Hathod) with 36.17°C, ward no. 12 (Maniywas) with 35.48°C, ward no. 48 (Jamdoli) with 33.76°C and ward no. 14 (Durgapura) with 33.56°C. Moderate mean LST were observed in ward no.
40 (Chandpole) with 32.08°C, ward no. 15 (Kartarpura/Kartarpura Industrial area) with 32.37°C and ward no. 45 (Badi Choupad) with 32.37°C etc. Relatively lowest temperature were found in the wards of ward no. 52 (Badanpura) with 31.25°C, ward no. 59 (Gangauri Bazar) with 31.30°C (Detailed statistics of ward wise mean LST has been enclosed as Appendix 9).

4.5 SPATIO-TEMPORAL ANALYSIS OF LST CHANGES

The seasonwise changes of spatial patterns of LST in relation to general LULC patterns have been compared in Figure 4.15. Spatial patterns of LST exhibit significant variation in terms of intensity as well as distribution from season to season. LST patterns of same season also exhibit significant changes over the study period i.e. from 2000 to 2011. In the month of February/March, the overall LST is low as compared to May and October. October, 2000 and May 2011 are recorded highest temperature.

![Figure 4.15: Seasonwise change in mean LST of JMC area (2000-2011)](image)

Pixel level mean LST intensity has recorded an overall increase in 2011 as compared to 2000 for March and May temperatures. Highest positive change has occurred in temperatures of May recording an increase of 2.63°C overall
mean. Increase in temperature in the month of March has been relatively low (1.42°C). Interestingly, contrary to this trend, temperature of month of October has declined by 6.89°C in 2011 as compared to October 2000. This may be attributed to heavy rainfall till 2008 to 2011 as compared to 2000.
Overall results show that the maximum change in mean LST has occurred in peripheral wards of the core city. Maximum mean LST changes have occurred in ward no. 02, 28, 29, 48 and 69 etc. amounting to above 2°C in
month of March. In May the increase is even higher amounting to above 3°C in ward no. 02, 28, 29 etc due to built up and scrub/bare soil land cover and lack of greenery in new areas.

4.5.1 Change analysis of ward wise mean LST in March (spring season)

Figure 4.17 shows the changes of ward wise mean LST over the period from 05th March 2000 and February 28th 2011. Increase in ward wise mean LST has been highest in ward no. 23 (4.43°C) and ward no. 12 (4.16°C). These wards have undergone considerable LULC change, sparsely vegetation to low dense built up areas and low dense built up to high dense built up areas. Thus alteration in natural surfaces leads to change in LST characteristics. It has also been observed that there is a slightly decrease in mean LST of some wards over the span of 11 years. Ward no. 48 recorded 1.09°C decline in mean LST followed by ward no.7 with a decline of 0.38°C, ward no.1 decline of 0.33°C and ward no. 27 decline of 0.32°C. These areas of decline in mean LST primarily correspond to the agriculture cropland and sparse vegetation areas. Hence, changes in LULC leads to increase or decrease in surface temperature.

![Figure 4.17: Wardwise decadal change in mean LST of March/February (2000-2011)](image-url)
4.5.2 Change Analysis of ward wise mean LST in May (summer season)

In the month of May the mean LST is very high. Figure 4.18 shows the changes of ward wise mean LST from 24th May 2000 and 31st May 2011. Both the images used for change analysis cover the same extent. All wards of the city have invariably recorded an increase in mean LST. Summers have become hotter for the city over the decade. The highest mean LST has been observed in ward no. 29 with 3.63°C and ward no. 2 with 3.46°C. Notably, over the decade these wards have observed considerable changes in their LULC configuration especially from vegetation to low dense built up areas and low dense built up areas to high dense built up areas. In some wards the increase in LST has been relatively low viz. ward no. 66 an increase of 1.78°C, followed by ward no.9 with an increase of 1.75°C, ward no. 43 with an increase of 1.62°C and ward no.7 with an increase of 1.75°C. Low increases in mean LST were observed in the water bodies and vegetated areas (dense vegetation and sparse vegetation) especially in extremely north-eastern part of the city.

![Figure 4.18: Wardwise decadal change in mean LST of May (2000-2011)](Image)

4.5.3 Change analysis of ward wise mean LST in October (autumn season)

Figure 4.19 shows that there was negative change in mean LST of all wards in this season from 15th October 2000 and 22nd October 2011. At ward
level too the mean LST was higher in 2000 as compared to 2011. There were -6.89°C mean LST changed recorded at ward level mainly attributed to rainfall. Rainfall has been the major factor for this negative change. Earlier the amount of rainfall was very less in this season but after 2008 the October month has receiving maximum heavy rainfall. Ward no. 25 with a decline of 10.35°C showed decrease in mean surface temperature, followed by ward no. 70 with a decline of 10.06°C, ward no.63 with decline of 9.39°C and ward no. 65 with decline of 9.36°C. These areas of decline in mean LST primarily correspond to the agriculture cropland and vegetation areas.

![Figure 4.19: Wardwise decadal change in mean LST of October (2000-2011)](image)

### 4.6. IDENTIFICATION OF VULNERABLE AREAS

Spatial distribution of LST has been examined in terms of Getis-Ord Gi* statistic. Hot Spot Analysis (Getis-Ord Gi*) tool identifies statistically significant spatial clusters of high values and low values. A new output feature class is created with a z-score and p-value for each feature in the input feature class i.e. ward wise mean LST intensity map. These values are measures of statistical significance feature by feature. A high z-score value and a small p-value for a feature indicate spatial clustering of high values (hot spots). A low negative z-value and a small p-value indicate a spatial clustering of low values.
(cold spots). The higher (or lower) the z-score, the more intense the clustering. A z-score near zero indicates no apparent clustering. Since LST is a continuous phenomenon which is not bound by administrative boundaries it has been considered more appropriate to identify relatively high and low LST regions of the city for various years through hot spot analysis.

In present context, based on the hot spots and cold spots as indicated by Gi* values, strong, marginal and weak mean LST wards have been delineated. Hot spots of mean LST represent high temperature cluster wards (western and southern wards) which corresponds to newly built up and bare/scrub land cover type. Cold spots represent low temperature cluster wards of mean LST which corresponds to vegetated and water land cover classes (especially central wards). Gi* values near zero indicate that there is no concentration of extremely high and low mean LST values and that mean there were not a cluster exists.
Figure 4.20: Seasonwise decadal changes in location of LST hot spots and cold spots.
The chapter shows that satellite derived LST values (day time) and mean LST at ward level. It is seen that LST values are in good agreement and found ± 3ºC to ± 6ºC change at ward level with different seasons. The heterogeneity and complexity of composition, pattern and spatial extent of LULC have also been noticed in some wards.
REFERENCES


LANDSAT 5 TM & LANDSAT-7 ETM+ user handbook.


