# Spatial Trends of Land Surface Temperature Variation Over Selected Urban Regions in Sri Lanka Using Remote Sensing

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**Abstract**

Increase of temperature in urban areas is a vital issue in most part of the world with urbanization. Land surface temperature (LST) varies with the nature of different urban surfaces. Most urban areas of the Sri Lanka possesses a messy urbanization or urban sprawl according to World Bank creating many issues like increase of urban temperature. Studies on land surface temperature over urban areas except Colombo is rarely found in Sri Lanka.

This study aims to detect spatial trends of LST over some selected urban areas (Kurunegala, Trincomalee, Anuradhapura and Badulla) in Sri Lanka from 1988 to 2016. LST is derived using Landsat images of 1988, 1997, 2000, 2010 and 2015 and Q GIS and ERDAS is used to calculate LST. Zonal statistics and spatial autocorrelation in ArcGIS is used to identify different vulnerability levels and spatial analysis.

Accordingly area of temperature more than $30^0$C has increased considerably by 2010 in Anuradhapura and southern part is highly vulnerable for higher temperature. Spatial pattern of temperature in Kurunegala seems followed by transport network of the area that higher temperature can be witnessed along and beside Colombo, Negambo, Puttalam and Dambulla roads. Higher temperature in Trincomalee urban council is distributed in Trincomalee town area and suburbs. In case of Badulla urban council same as in Kurunegala, initially area with higher temperature can be seen in the middle of city and by 2015 vulnerability has spread along and beside Mahiyanganaya road and A5 road as the city grows up. These results can be considered in urban planning, designing and policy making so as to minimize the vulnerability and bring out strategies for mitigating the vulnerability of higher temperature since these urban areas is still growing.

**Key words:** Landsat, ERDAS, Q GIS, Spatial Autocorrelation, Zonal Statistics

## 1. Background of the Study

Land Surface Temperature is one of the key parameters that help to determine the variability of climate change from local to global level. Global mean temperature is predicted to be increased by1.4 $^0$C to 5.8$^0$C in 2100 when compared to the year 2000 according to Intergovernmental Panel on Climate Change (Fung, Lam, Hung, Pang, & Lee, 2006). As well Sri Lanka is also experiencing an increase of temperature as per the records of Department of Meteorology, Sri Lanka. Accordingly there is a considerable increase in average annual surface temperatures across the country during recent time showing a similar trend to the global trend of rising temperature during the last century.

Higher rates of urbanization has resulted in not only urban demographic, economic, land use and land cover changes, but also resulted in micro climate changes in urban areas. Concentration of secondary and tertiary economic activities, expansion of built-up areas and low vegetation cover, large number of vehicle population and fuel consumption are some of the prominent features generate higher land surface



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temperature causing micro-climate warming in urban environment. These heat trapping sources are associated with higher land surface temperature than the surrounding environment. This is called Urban Heat Island (UHI) effect where temperature in urban centers is higher than the rural surroundings (Buyadi, Mohd, & Misni, 2013). UHI generates number of local problems such as biophysical hazards like heat stress, air pollution and associated public health problems (Ahmed, Kamruzzaman, Zhu, Rahman, & Choi, 2013).

According to World Bank reports Sri Lanka is owned by a messy urbanization pattern reflecting urban sprawl and ribbon development with rapid growth along transport corridors. This messy urbanization pattern is associated by large number of slums and shanties. This pattern has led to many socio-economic and environmental issues in urban regions including increased land surface temperature. Yet most of the studies focus on LST variation in Colombo district. Manawadu, 2012 identifies higher level of LST in the areas like New Bazar, Kochchikade South, Gintupitiya, Masangas Weediya, Aluthkade and Panchikawatte in case of Colombo MC. Hence this study addresses the issue on urban micro climate warming determining the spatial trends of land surface temperature variations over some selected growing cities including Kurunegala MC, Badulla MC, Anuradhapura MC and Trincomalee UC.

There are different approaches to assess trends of LST in urban areas. Ground measurements which are basically based on point values cannot practically provide values of LST over wide areas. One of the very efficient ways to measure LST over the entire globe with high temporal resolution is satellite remote sensing (Li *et al*., 2013). It is evident that most of the studies have used Landsat data for retrieving LST in different regions. Ahmed *et al*., 2013 uses Landsat images of 1989, 1999 and 2009 for simulating land cover changes and their impacts on land surface temperature in Dhaka, Bangladesh. He uses Landsat images for measuring LST as well for identifying landuse and landcover changes. Buyadi *et al*., 2013 also uses Landsat images of 1991 and 2001 to assess the impact of land use changes on the surface temperature distribution of area surrounding the National Botanic Garden, Shah Alam. The relationship between land cover changes and spatial-temporal dynamics of land surface temperature in Isfahan is determined by Falahatkar S *et al*., 2011 using Landsat thermal images in 1990 and 2001 .This study utilizes satellite imagery of Landsat 5 TM, landsa7 ETM+ (Band 06-Thermal Band) and Landsat 8 OLS/TRIS (Band 10 and 11-Thermal Bands) for retrieving LST for determining the spatial trends of LST. In this context, spatial trends of land surface temperature (LST) in some selected urban regions in Sri Lanka is assessed to identify most vulnerable areas to encourage mitigation strategies to extend the urban living condition.

## 2. Research Objectives

The main objective of this study is to identify the spatial trends of land surface temperature (LST) variation in growing cities in Sri Lanka.

Specific objectives of this study are:

1 Calculating LST over selected urban areas using thermal remote sensing from 1988 to 2015 and mapping

2 Assessing the spatial trends and patterns of detected LST variations over selected cities and identify the vulnerable regions exposed to higher urban temperature levels.

## 3. Research Methodology

Design of the research outlines different stages and methods carried out to identify the trends of land surface temperature over selected urban areas in Sri Lanka (Figure 1). Research design is developed considering based on five categories. Data collection section indicates collected data for different purposes. Data processing includes all methods applied

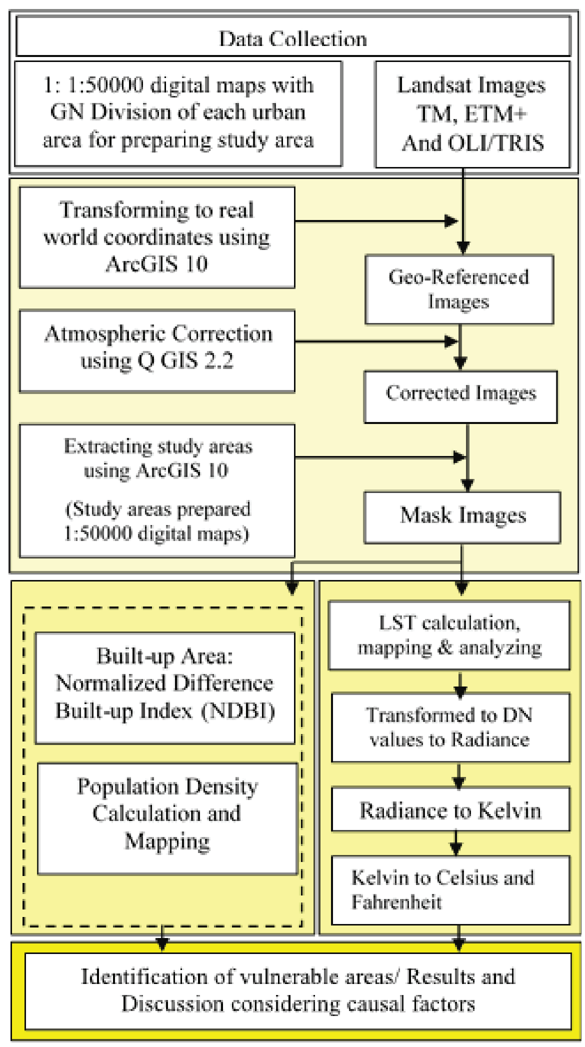


Figure 1. Research Design.

Table 1. List of Satellite Images used in the study.

| Urban Area | Satellite | Sensor | Data acquisition | |
|---|---|---|---|---|
| | | | Date | Path/row |
| **Kurunegala** | Landsat 5 | TM | 1988.12.15 | 141/55 |
| | Landsat 5 | TM | 1997.02.07 | |
| | Landsat 7 | ETM+ | 2002.11.28 | |
| | Landsat 5 | TM | 2010.02.27 | |
| | Landsat 8 | OLI/TIRS | 2015.01.08 | |
| **Badulla** | Landsat 5 | TM | 1988.12.15 | 141/55 |
| | Landsat 5 | TM | 1997.02.07 | |
| | Landsat 7 | ETM+ | 2000.01.23 | |
| | Landsat 5 | TM | 2010.08.06 | |
| | Landsat 8 | OLI/TIRS | 2015.01.08 | |
| **Anuradhapura** | Landsat 5 | TM | 1988.12.15 | 141/54 |
| | Landsat 5 | TM | 1997.01.22 | |
| | Landsat 7 | ETM+ | 2000.1.23 | |
| | Landsat 5 | TM | 2010.02.27 | |
| **Trincomalee** | Landsat 5 | TM | 1988.04.03 | 141/54 |
| | Landsat 5 | TM | 1994.09.11 | |
| | Landsat 7 | ETM+ | 2001.09.06 | |
| | Landsat 5 | TM | 2010.08.06 | |
| | Landsat 8 | OLI/TIRS | 2015.09.21 | |

including gross check, atmospheric correction and extracting images. LST calculation and mapping trends summarizes steps adopted in calculating LST and mapping whereas identifying the changes of built-up area using NDBI parameter and population density calculation indicated in the next section. Determining the relationships, correlations with some causal factors when discussing the results is put forwarded in the last section in the research design.

This study is performed based on remote sensing techniques that Landsat satellite images are used to measure LST. Most of the researches rectify using Landsat images for calculating LST. Ahmed *et al*., 2013 uses Landsat images of 1989, 1999 and 2009 for simulating land cover changes and their impacts on land surface temperature in Dhaka, Bangladesh. Buyadi *et al*., 2013 also uses Landsat images of 1991 and 2001 to assess the impact of land use changes on the surface temperature distribution of area surrounding the National Botanic Garden, Shah Alam. The relationship between land cover changes and spatial-temporal dynamics of land surface temperature in Isfahan is determined by Falahatkar S *et al*., 2011 using Landsat thermal images in 1990 and 2001. Manawadu L, 2012 uses Landsat images for measuring temeprtaure in Colombo.Landsat data utilized in this study is given in Table 1 and these images were downloaded from USGS exploer site, USA.

Firstly gross check was done manually to find out the images without cloud covering the selected urban region. Then atmospheric correction was done using Semi –Automatic Classification plugin in Q GIS 2.2 version.

Similar method is used to measure LST from Landsat 7 ETM+ and Landsat 5 except some parameters and calibration constants. And different algorithm is used to extract temperature from Landsat 8 images. There are two thermal bands in Landsat 8. Hence LST is calculated using both bands and mean is considered as final LST. Thermal bands of each satellite image (band 6 in Landsat 7 and Landsat 5 and Band 10 and 11 in Landsat 8) are used to calculate LST.

When estimating the surface temperature firstly linear equation model is used to convert the DN into radiance temperatures. Similar equation is used to convert digital numbers to spectral radiance from Landsat 5 and Landsat 7(equation 1) and another equation is utilized for Landsat 8 (equation 3).

$$CV_R = G\,(CV_{DN}) + B \qquad \{\text{Equation 1}\}$$

Where:

$CV_R$ is the cell value as radiance

$CV_{DN}$ is the cell value digital number

G is the gain

B is the bias (or offset)

This formula can be simplified as:

Radiance = Gain * DN + Offset

This can be expressed as given in equation 2.

Radiance = (($L_{MAX}$ – $L_{MIN}$) / ($QCAL_{MAX}$ –$QCAL_{MIN}$)) * (QCAL – $QCAL_{MIN}$) + $L_{MIN}$ {Equation 2}

Where:

$L_{MAX}$ is the Spectral Radiance Range or high gain for specific band at digital numbers 0 or 1 and 255

$L_{MIN}$ is the Spectral Radiance Range or low gain for specific band at digital numbers 0 or 1 and 255

$QCAL_{MIN}$ is the value, which can be the lowest among DNs

$QCAL_{MAX}$ is the value, which can be the highest among DNs

QCAL is the Digital Numbers

(These values can be obtained from the MLT file downloaded along with the Landsat images)

For converting the raw bands of Landsat 8 into Top of Atmosphere Radiance (TOAr) equation 3 is used.

y = mx + b {Equation 3}

Where,

y is $TOA_r$ (Similar as $CV_R$ in equation 1)

m is the Radiance Multiplier

x is the raw band

b is the Radiance Add.

(These values can be obtained from the MLT file downloaded along with the Landsat images)

Spectral Radiance values were converted to a brightness temperature value using the equation 4. It is common for all three sensors.

$$T_s = \frac{K2}{In\left(\frac{K1}{CV_R}+1\right)} \quad \text{\{Equation 4\}}$$

Where:

$T_s$ is surface temperature in Kelvin

K1 and K2 are calibration constants chosen to optimize the approximation for the band pass of the sensor.

K1 and K2 are calibration constants, which can be obtained from MLT files.

Table 2. Emissivity Values Used in Different Land Surfaces.

| **Land surface** | **Emissivity *e*** |
|---|---|
| Bare Soil | 0.93 |
| Vegetation | 0.98 |
| Built-up | 0.94 |
| Water | 0.98 |

Sources: (http://fromgistors.blogspot.com/2014/01/estimation-of-land-surface-temperature.html)

Emissivity is an important factor to consider in calculating LST. Up to the above process only brightness temperature is calculated. Land surface emissivity is used to convert brightness temperature in to land surface temperature. Q GIS provides guidelines to calculate emissivity raster (http://fromgistors.blogspot.com/2014/01/estimation-of-land-surface-temperature.html). First land cover classification is done using Q GIS 2.2 using the categories as vegetation, built-up, bare soil and water. Secondly emissivity values are assigned into each category as indicated in Table 2 reclassifying the raster. To calculate actual LST from Satellite temperature equation 5 is used.

b / (1 + (10.8 * b / 14380) * ln (a)) {Equation 5}

Where;

b is the brightness temperature raster

a is the emissivity raster

Then Land surface Temperature raster is retrieved in Kelvin scale. To convert Kelvin scale into Celsius 273.15 is subtracted from the above raster data set generating a raster file of LST in Celsius. ArcGIS 10 was used to map to identify spatial trends and patterns of LST and this study uses zonal statistics to determine mean LST by GN Divisions and to detect the vulnerable GN Divisions to higher temperature levels. Furthermore spatial autocorrelation is used to analyze spatial pattern of LST.

Normalized Difference Built-up Index (NDBI) is also used to identify the built-up cover and determine the relationship of LST and Built-up area. Equation 6 is used to calculate NDBI. Relationship between LST and NDBI was tested using Polinomial regression model in MINITAB 16.

NDBI = (medium IR - near IR band) / (near IR band + medium IR) {Equation 6}

## 4. Results and Discussion

**Spatial Trends of LST variations in Kurunegala MC**: Spatial distribution of LST in Kurunegala MC from 1988 to 2015 is demonstrated by Figure 2. Accordingly there is a

Table 3. Correlation & Regression Statistics of NDBI and LST in Kurunagala MC.

| Year | Pearson Corelation | P-vaue | R square | Anova P-vaue |
|---|---|---|---|---|
| 1988 | 0.627 | 0.000 | 42.4% | 0.000 |
| 1997 | 0.658 | 0.000 | 44.0% | 0.000 |
| 2002 | 0.791 | 0.000 | 63.0% | 0.000 |
| 2010 | 0.498 | 0.000 | 26.8% | 0.000 |
| 2015 | 0.780 | 0.000 | 61.8% | 0.000 |

Source: Prepared by Author, 2016

clear pattern of the spatial distribution of temperature in Kurunegala MC Area that critical areas exposed to higher temperature are concentrated into the center of the city and corridor which connects Puttalam road, Negambo Road, Colombo road and Kandy road. Amongst them most vulnerable areas lie between Colombo and Puttalam roads. Most of these areas are exposed to a temperature exceeding $28^0$C. This may be because of the expansion of the city focusing those transport corridors. Area exposed to the highest temperature level ($30^0$C<) is increasing slightly with time span. Spatial pattern of LST in Kurunegala MC is a significant clustered pattern as derived by the results of spatial autocorrelation (Z-score 16.5945 & P-value 0.0000). GN divisions including Kurunegala Town North, Kurunegala Town – Bazaar, Kurunegala Town – Central, Kurunegala Town – West, Kurunegala Town – South, Udawalpola, Gangoda and Ilippugedara are exposed to higher temperature levels. Population density is also higher in the GN divisions with higher temperature level. There is a significant positive relationship between NDBI and LST as given in Table 3.

**Spatial Trends of LST variations in Badulla MC**: Spatial distribution of LST in Badulla UC is mapped in Figure 3. Accordingly majority of the area is experiencing a temperature less than $24^0$C whereas the Badulla town area having a temperature more than 26 $^0$C in each year. There is rare difference in the temperature variation in Badulla UC from 1988 to 2000. Yet there is a considerable increase of the area undergoing higher temperature levels with the time factor. Area which is undergoing a temperature between

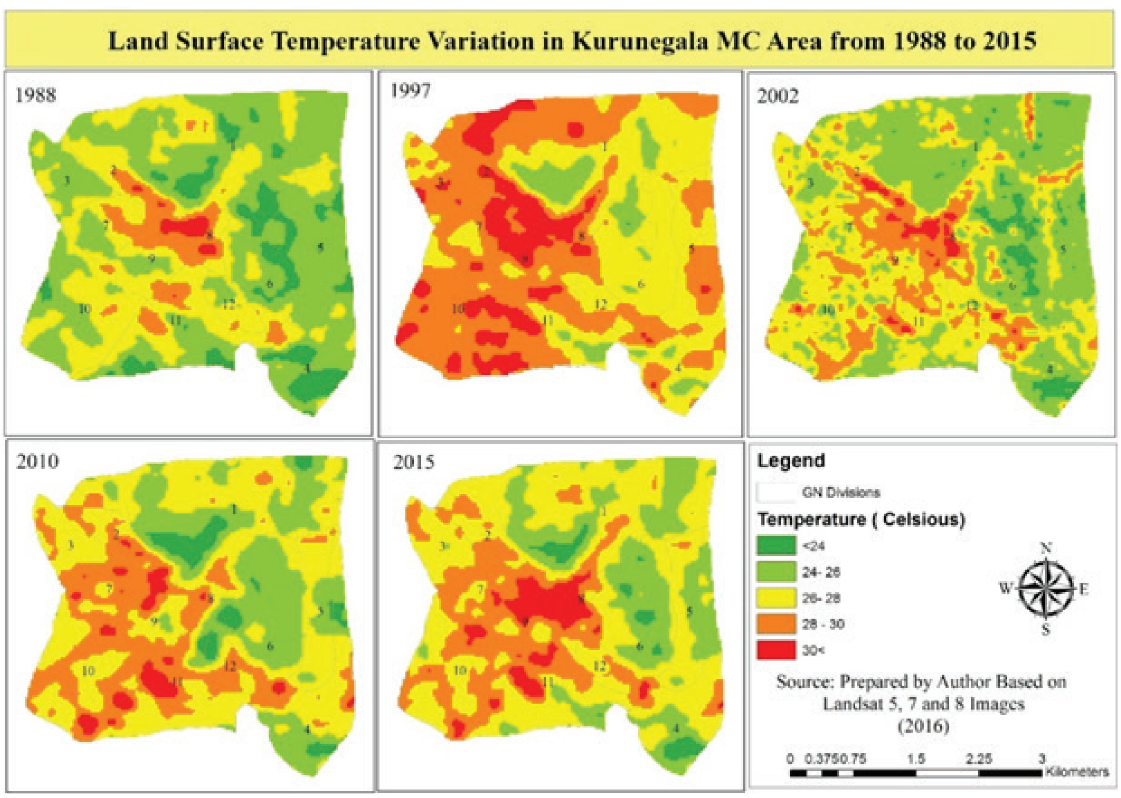


Figure 2. LST Variation in Kurunegala MC from 1988 to 2015.

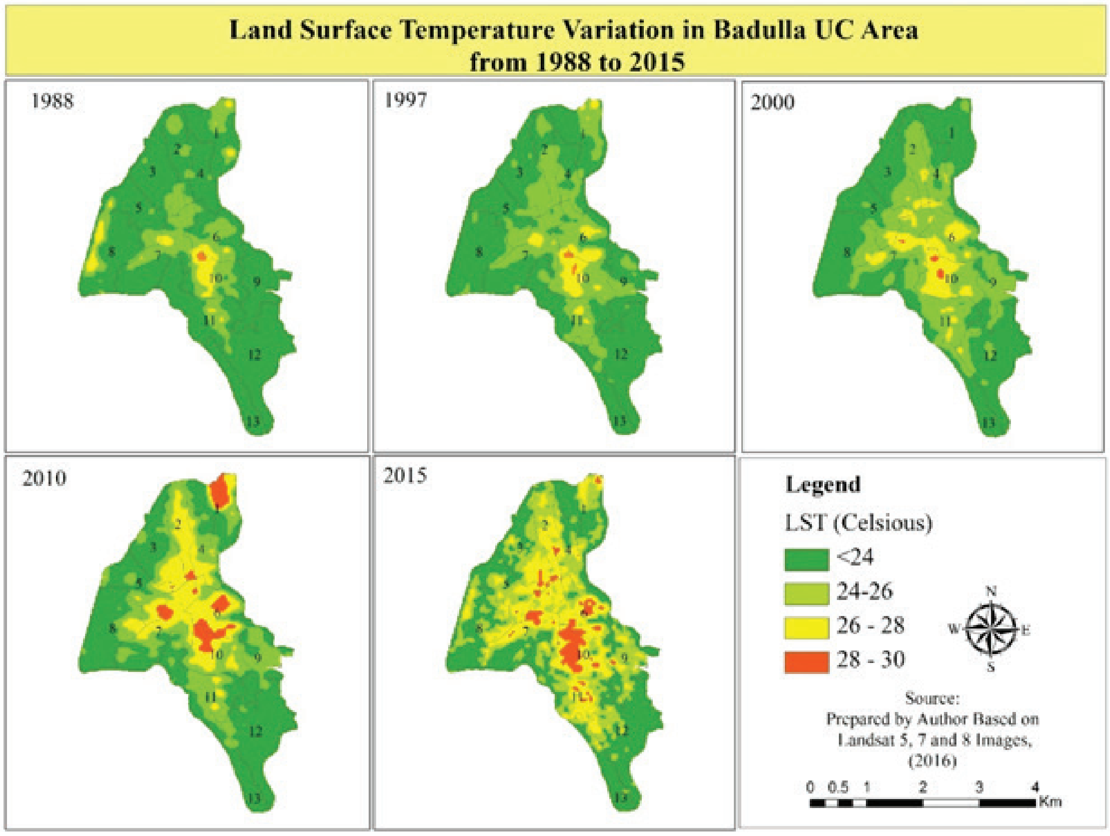


Figure 3. LST Variation in Badulla MC from 1988 to 2015.

Table 4. Correlation & Regression Statistics of NDBI and LST in Badulla MC.

| Year | Pearson Correlation | P-value | R square | Anova P-value |
|---|---|---|---|---|
| 1988 | 0.633 | 0.000 | 41.0% | 0.000 |
| 1997 | 0.655 | 0.000 | 44.0% | 0.000 |
| 2000 | 0.663 | 0.000 | 45.2% | 0.000 |
| 2010 | 0.715 | 0.000 | 54.2% | 0.000 |
| 2015 | 0.688 | 0.000 | 54.7% | 0.000 |

$26^0$C and $28^0$C is expanding with the passage of the time. The expansion of areas with higher temperature seems generally directing from middle to north. This may be because of the expansion of the city along Mahiyanganaya road which leads to North direction. And also westward and downward expansions of higher temperature corridors are also important which seems followed by Batticaloa highway (A5 road). Spatial pattern of LST is also a clustered pattern ((Z-score 9.2322 & P-value 0.0000). Badulupitiya and Badulla East GN divisions exist under higher temperature zone from 1988 to 2015. In 1988 these two GN divisions experienced a temperature of 24-26 $^0$C. Badulla East is under the impact of the temperature level of $26^0$C-28 $^0$C from 2000 to 2015. And Badulla North and Badulla Central are also experiencing a higher temperature level of $26^0$C-28 $^0$C. It is clear that with the passage of time most parts of Badulla MC Area are exposing to higher temperature focusing North and Western directions. This trend is highly correlated with the population density of the area (Figure 4). The areas with higher temperature have higher population density. It seems built-up areas also affected on increased LST levels. Built up area is also increasing in Badulla MC with the passage of time and there is a considerably strong positive relationship between NDBI and LST and R2value is increasing from 41% (1988) to 55%(2015)(Table 4).

**Spatial Trends of LST variations in Anuradhapura MC**: There is a significant variation in the distribution of LST in Anuradhapura MC (Figure 5). In 1988 only a considerable area has undergone higher temperature. Initially area surrounded by the airport of Anuradhapura records the higher temperature. By 1997 area covered by higher temperature

Source: Prepared by Author, 2016

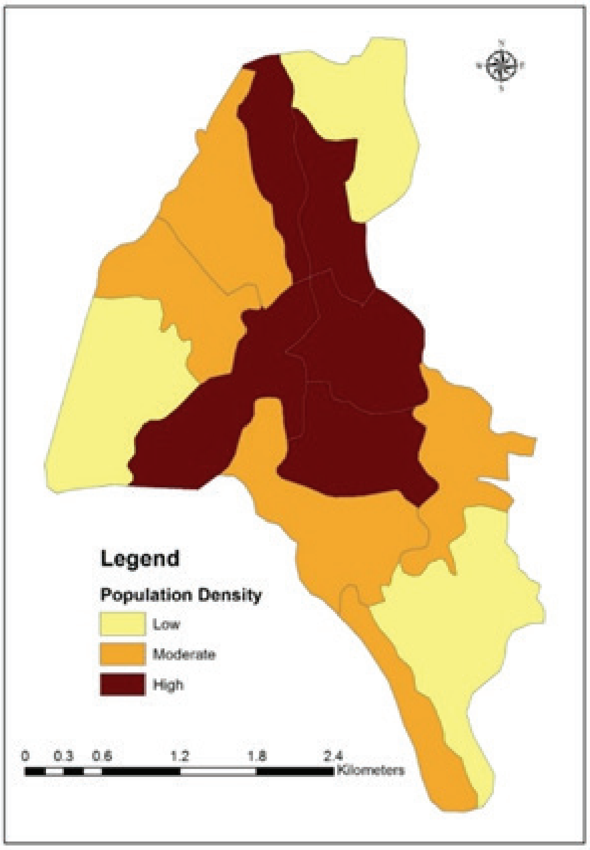


Figure 4. Population Density of Badulla MC in 2012.

has gradually spread out around airport area, town area and as well some areas of sacred city. By 2000 this pattern further broadening that it seems correlated with the road network of the area. Higher vulnerability can be seen along and between A13 and A12 roads. And in the upper part of the area records higher temperature concentrating A20 and A12 roads. Vulnerable area has dispersed further more along same corridors by 2010 showing a highlighting higher LST distribution in the Western part of Anuradhapura UC (Sacred City). There is a clear pattern of the spatial distribution of LST in Anuradhapura UC that vulnerability to higher temperature is spreading from South East to North Western and North Eastern directions with the passage of time (Figure 6). Step 2 part 2, Step2 part 1, Step 2 part 3, Step 3 part 3, Step 2 part 4, Step 3 part 1, Wannithammannawa, Step 3 part 2 and Shuddha Nagaraya are highly vulnerable for higher temperature levels. Most of these areas with higher

Table 5. Correlation & Regression Statistics of NDBI and LST in Anuradhapura MC.
Source: Prepared by Author, 2016

| Year | Pearson Correlation | P-value | R square | Anova Pvalue |
|---|---|---|---|---|
| 1988 | 0.717 | 0.000 | 57.00% | 0.000 |
| 1997 | 0.763 | 0.000 | 63.80% | 0.000 |
| 2000 | 0.768 | 0.000 | 61.50% | 0.000 |
| 2010 | 0.857 | 0.000 | 75.70% | 0.000 |

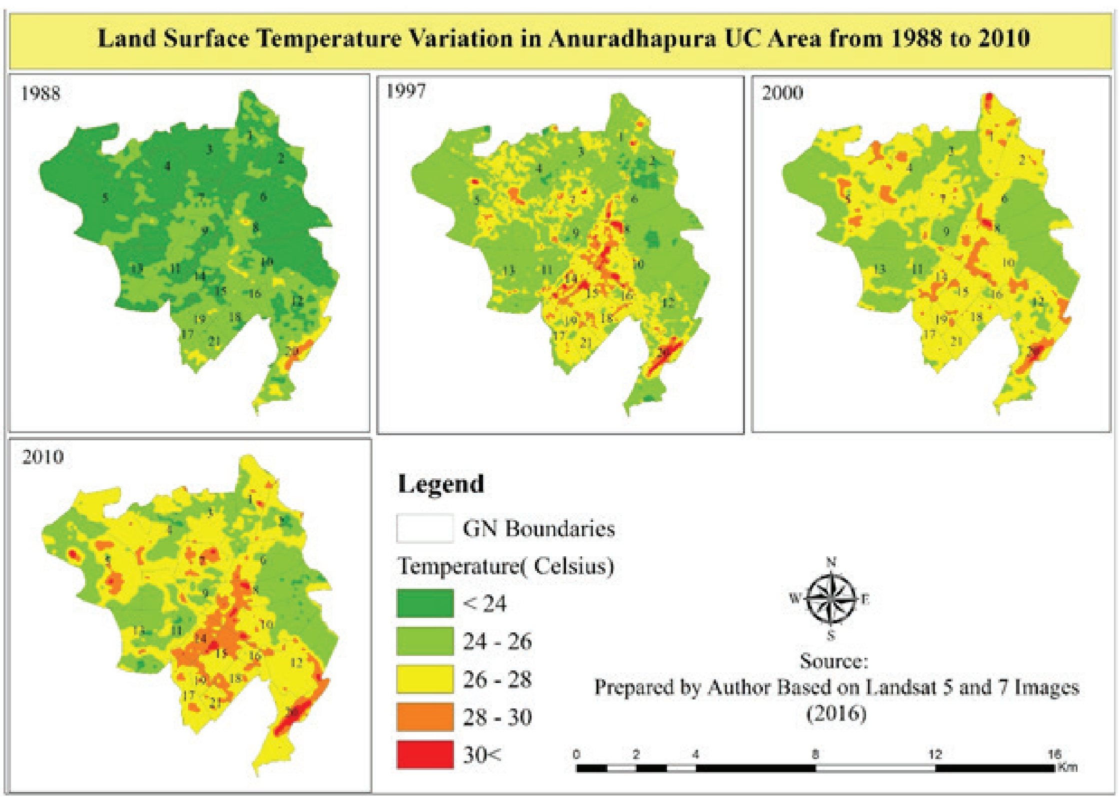


Figure 5. LST Variation in Anuradhapura MC from 1988 to 2010.

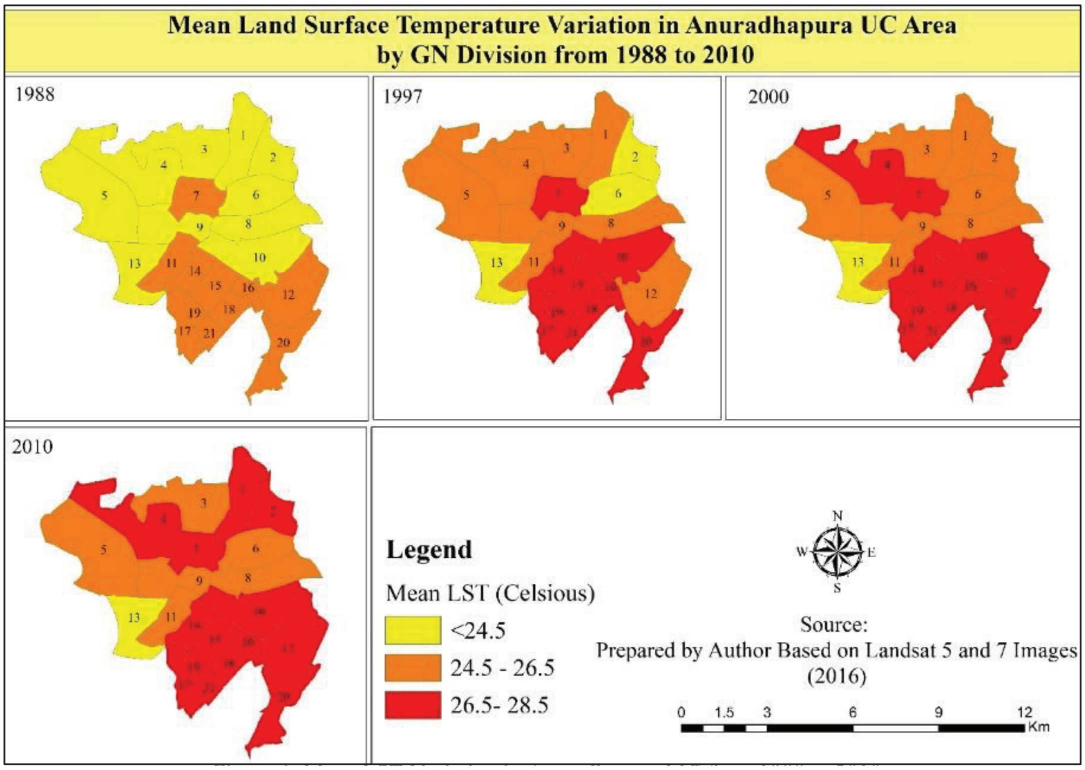


Figure 6. Mean LST Variation in Anuradhapura MC from 1988 to 2010.

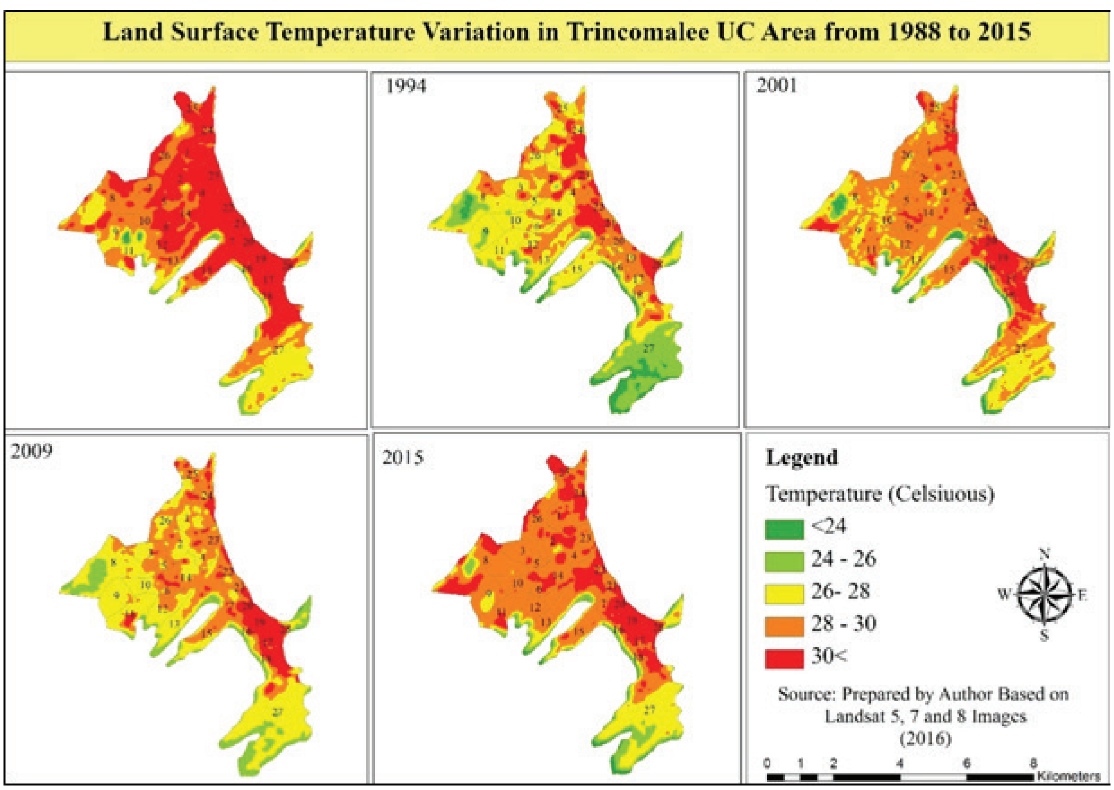


Figure 7. LST Variation in Trincomalee UC from 1988 to 2015.

Table 6. Correlation & Regression Statistics of NDBI and LST in Trincomalee MC.

| Year | Pearson Correlation | P-value | R square | ANOVA P-value |
|---|---|---|---|---|
| 1988 | 0.699 | 0.000 | 50.5% | 0.000 |
| 1994 | 0.689 | 0.000 | 47.5% | 0.000 |
| 2001 | 0.737 | 0.000 | 55.8% | 0.000 |
| 2010 | 0.599 | 0.000 | 36.2% | 0.000 |
| 2015 | 0.778 | 0.000 | 69.4% | 0.000 |

temperature are correlated with areas with higher population density. As well, built-up areas also seem affected on this spatial distribution of LST. Relationship between LST and NDBI is positive and significant when considering Pearson correlation and regression values (Table 5).

**Spatial Trends of LST variations in Trincomalee UC**: Most parts of Trincomalee UC records a temperature more than 28$^0$C as illustrated in Figure 7. Amongst them a considerable portion of the area is under a temperature more than 30$^0$C. Eastern coastal region is remarkably vulnerable for higher temperature where Trincomalee town area is also spreading into the same direction. Most southern part where Trincomalee Naval Dockyard is located closer by remains with the lowest temperature during each year having a dense vegetation cover. In 1988 only Poompuhar remains with low temperature category with a mean LST less than 27$^0$C whereas Singhapura, Linganagar and Manayaveli GN divisions receive an average of 27$^0$C- 28$^0$C. All the other GN divisions in Trincomalee UC are exposed to higher temperature which is more than 30$^0$C in 1988. Generally Manayaveli GN division is under low vulnerability to higher temperature in all years. Even in the occasions average temperature over the entire area is comparatively low, the above mentioned areas record higher levels of LST. As a whole, GN divisions in the Eastern part of the UC area are highly vulnerable for higher temperature levels exceeding 30 $^0$C (Figure 8).Among them are Peruntheru, Arasady, Thirukadaloor, Pattanatheru, Uppuveli, Murugapuri, Sivapuri, Salli, Puliyankulam, Abayapura, Selvanayahapuram, Palaiyoottu, Jinnanagar, Anpuvalipuram, Sonagavadi, Mihindapura, Varothayanagar, Villundy and Arunagirinagar. It is clear that population density is also higher in these areas and there is a significant positive relationship between LST and NDBI (In 2015 $R^2$=69.4%/P-value=0.000) that built-up areas may also be a causal factor for increased LST in these regions (Table 6).

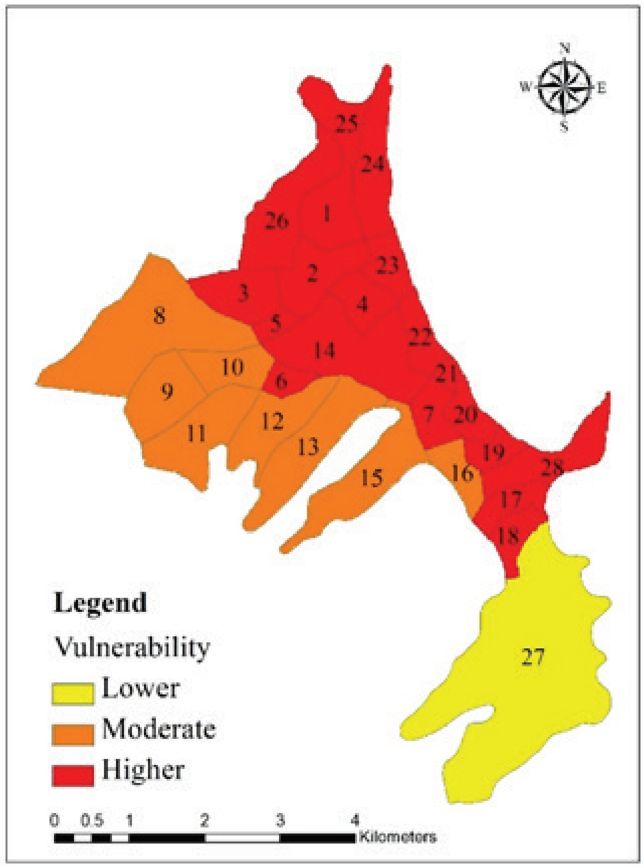


Figure 8. Vulnerability to LST in Trincomalee UC.

## 5. Conclusion

In Kurunegala MC, critical areas exposed to higher temperature are concentrated into the center of the city and corridor which connects Puttalam road, Negambo Road, Colombo road and Kandy road. Amongst them most vulnerable areas lie between Colombo and Puttalam roads. In Badulla MC, area exposed to higher temperature is expanding with the time span. The expansion of areas with higher temperature seems generally directing from middle to north (along Mahiyanganaya Road) and western (A5 road) directions along major transport networks.Distribution of LST in Badulla is closer to clustered pattern according to spatial autocorrelation results. In Anuradhapura MC, area affected by higher temperature is broadening that it seems correlated with the road network of the area. Spreading directions are from South East to North Western and North Eastern directions with the passage of time. In Trincomalee

UC, eastern coastal region is remarkably vulnerable for higher temperature where Trincomalee town area is also spreading into the same direction. GN divisions in the Eastern part of the UC area is highly vulnerable for higher temperature levels exceeding 30 $^{0}$C. There are many causal factors affecting on higher LST levels in all of the selected urban regions including higher population density, increased built-up areas and road network. More studies are recommended on temporal variation of LST with respect to different seasons and day and night for predictions as well as more studies on probable causal factors. Most vulnerable areas detected by this study can be prioritized for initiating sustainable urban planning and designing to mitigate the worst case scenarios as these cities are still growing.

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