# Identification of Urban Heat Islands &Its Relationship withVegetation Cover: A Case Study of Colombo & Gampaha Districts in Sri Lanka

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Date Received: 12-05-2017 Date Accepted: 05-11-2018

**Abstract**

Global Warming is a major environmental problem that all kind of organisms has been affected at present. Urban Heat Island (UHI) is one of primary impacts of Global Warming. UHI is a phenomenon that the temperature of urban area is higher than surrounding rural areas or suburban areas. This increasing trend of temperature in urban areas affects many environmental entities such as air quality, water resources, habitats behaviors and climate changes. The most remarkable incident that relate with UHI is the difference of thermal properties of the surfaces. Many countries experience the consequences of Urban Heat Islands in many aspects such as economic, health, social and environmental affects. Thus to mitigate such impacts of UHI, it is very important to identify the main reasons behind this. In this paper UHIs in Colombo, Gampaha Districts and the relationship between UHI and vegetation cover were analyzed based on Landsat 8, 30m resolution data. Land Surface Temperature was derived from Landsat thermal Infrared band through several equations of United State Geological Survay (USGS) guidelines using Arc GIS 10. Conversion of Digital Number (DN) values to Top of Atmosphere (TOA) Radiance, Conversion of TOA Radiance to Satellite Brightness temperature and final calculation of Land Surface Temperature considering land surface emissivity are the steps that had been done for the analysis. Vegetation cover was derived by using vegetation index with the Red and Near Infra Red bands. The result shows that the land high surface temperature directly relates with the urbanized regions where vegetation cover is very less. High temperature difference could be identified that cause to arise the urban heat island effects in Colombo & Gampaha districts. There is a strong linearly negative correlation with correlation coefficient value of -0.742 between land surface temperature and vegetation cover. 78.8 $km^2$ (including water) of total area had been identified as NDVI value less than 0.1. And extent of high temperature area was 74.12 $km^2$ where temperature more than 27$^oC$ at 10.22am. The area in temperature range of 25-27 was 464.95$km^2$ and area in NDVI value range 0.1-0.2 was 333.04 $km^2$. 1471.1 $km^2$ was identified as NDVI value between 0.3-0.4 and the area at low temperature was 1529 $km^2$where temperature less than 25$^oC$. According to this results, high temperature at non-vegetated areas and low temperature at vegetated areas could be noted very clearly. This is probably due to the ecological function of vegetation that lay down the surface temperature from high evapotranspiration. Vegetated areas are mostly sensed with surface temperature.Thus research output can be useful for policy-makers and planners of development projects such as Western province Megapolis project as well as for general public to understand the urban heat island effects and importance of vegetation cover to mitigate such impacts.

*Keywords: Evapotranspiration, Global warming, NDVI, Thermal bands, Arc GIS*

## 1. Introduction

1.1 *The term of Urban Heat Island (UHI)*

One of prominent consequences of Global Warming is rapid increase of temperature in particular areas in addition to increase of the earth totally. These particular areas mostly belong to 'Urban' sites or built up areas where most parts of the land surface are covered with buildings and artificial entities.

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*Tel: ISSN 2235-9370 Print/ISSN 2235-9362 Online ©2017 University of Sri Jayewardenepura*

In addition to the urban structures, lots of reasons like emission of gases from vehicles and industries, high population density, less green patches, heavy machineries have caused to originate higher temperature sites called “Urban Heat Islands (UHI)”. According to the United State Environmental Protection Agency (US EPA) the term of "Heat Island" describes “built up areas that are hotter than nearby rural areas and the annual mean air temperature of a city with 1 million people or more can be 1.8-5.4°F (1-3°C) warmer than its surroundings”.

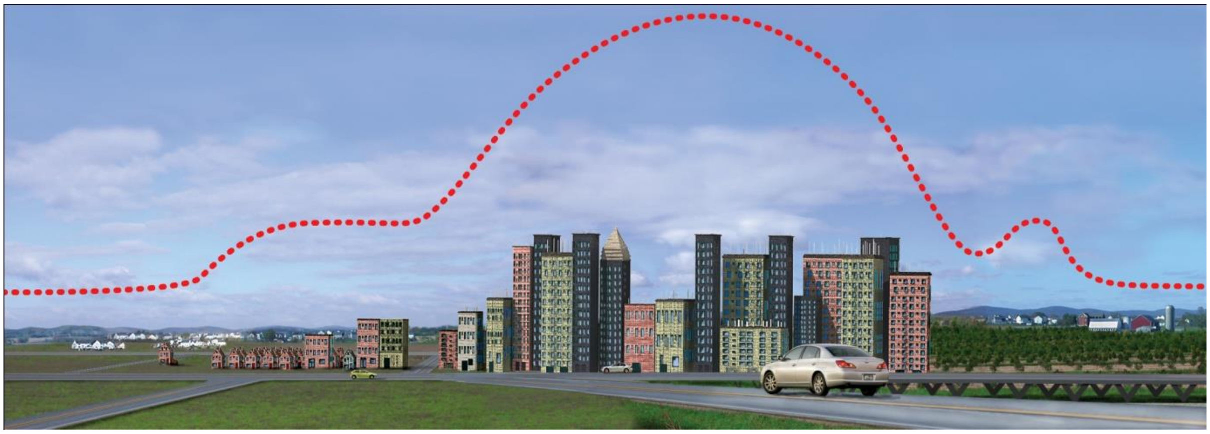

Figure 1: Temperature pattern of urban heat islands.
Source - http://www.nasa.gov/.

Evapotranspiration is the natural cooling system that caused to decrease the surface temperature naturally. Evapotranspiration is the process which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants.Theland surfaces in cities mostly are impervious, which causes runoff greater than natural surface in rural areas. Less vegetation cover and high rated runoff on impermeable surfaces cause reduce the soil moisture, shading and the rate of evapotranspiration in urban areas. Especially replacement of natural land surface by impermeable surfaces (built surfaces)reduces the vegetation and moisture-trapping soils which use a relatively large proportion of the absorbed radiation in the evapotranspiration process and release water vapors that contribute to cool the surrounding air. Thus more heat energy entering into air in urban area make the temperature rise rapidly.

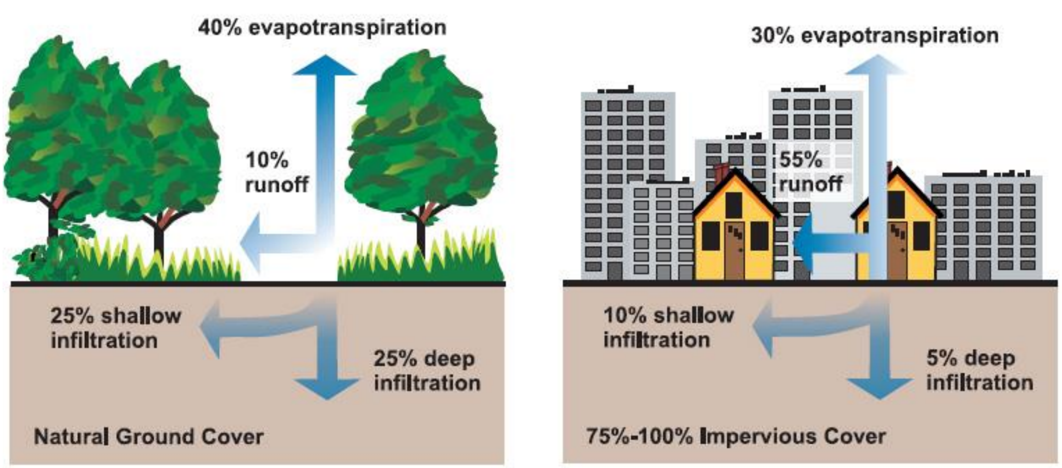


Figure 2: Impervious surfaces and reduced evapotranspiration.
Source–US EPA.

Built surfaces tend to absorb a significant proportion of incident radiation, which is released as heat. As well as the city construction materials including concrete, brick, tar and asphalt cause higher absorption of solar radiation and low albedo (low reflection) due to difference of thermal properties. These urban materials have also high heat capacity and they retain heat and slowly release at night. As well as anthropogenic heat which is released by industrial, vehicle traffic, power plants, airconditioners, andwaste heat productionsin urban areas isalso one ofthe other key factors of making UHIs. This additional heat caused the increase of temperature in night time.

Urban geometry is also one of key factors for forming UHIs which represent the building structures and space among the buildings in cities. The canyons structures cause to scatter the reflected radiance and create enhance the warming. During the day, solar energy is trapped by multiple reflections of the buildings while the infrared heat losses are reduced by absorption. And, high roughness structure is also problem of urban area, whichreduces the convective heat removal and transfer by wind (Vereda, 2007).

Air pollution and greenhouse gas emissions also cause to increase the temperature in urban areas. It is obvious that air pollutants, particularly aerosols that are abundant over polluted urban areas. These polluted air including aerosols and greenhouse gases absorb the large proportion of re-radiate long wave (infrared) radiation and inhibit the corresponding radiative surface cooling producing a pseudo-greenhouse effect, which isalso responsible for urban heat island effect.

Figure 3: Urban geometry (Canyon).

*1.2 Impacts of UHI*

Under the above mentioned factors it is obvious that the urban areas are normally warmer than the rural areas. Many countries experience the consequences of Urban Heat Islands in many aspects such as economic, health, social and environmental affects.Urban heat Islands increasesthe overall electricity demand for cooling in offices and homes. During extreme heat events, energy demand for cooling can be overloaded and it creates power outages.

UHI directly influence the human health of urban residents. When the day-night temperature difference is low the night temperature affects on people’s health in urban areas. Increased daytime temperatures, reduced nighttime cooling, and higher air pollution levels associated with urban heat islands can affect human health by contributing to general discomfort, respiratory difficulties, heat cramps and exhaustion, non-fatal heat stroke, and heat-related mortality. Within the United States alone, an average of 1,000 people die each year due to extreme heat. (Changnon et al,1996). As well as resulted heat of UHI, may affect a person's mobility, awareness, or behavior. Researchers have noted that individuals with cognitive health issues such as depression, dementia are more at risk when faced with high temperatures (Menne et al, 2004). Not only health, but heat can also affect behavior. A study of United State suggests that heat can make people more irritable and aggressive, noting that violent crimes increased by 4.58 out of 100,000 for every one degree increase in temperature. This situation may directly impact on the society. Heat islands can also exacerbate the impact of heat waves, which are periods of abnormally hot, and often humid, weather. Sensitive populations, such as children, older adults, and those with existing health conditions, are at particular risk from these events.Environmental point of view, UHI affect many entities such as air quality, water resources,habitats behaviors, climate and weather changes, etc. UHI directly cause to increase the concentration of air pollutants that affect air quality. These pollutants include volatile organic compounds, carbon monoxide, nitrogen oxides, sulfur dioxide, particulate matter etc. The production of these pollutants combined with the higher temperatures in UHIs can quicken the production of ozone. Ozone at surface level is considered to be a harmful pollutant (U.S. Department of Energy Report, 2014). And these pollutants contribute to complex air quality problems such as acid rain. As well as the quality of the water resources can be affected, because of the UHI. High pavement and rooftop surface temperatures can heat stormwater runoff. Tests have shown that pavements that are $100^{o}$ F ($38^{o}$ C) can elevate initial rainwater temperature from roughly $70^{o}$ F ($21^{o}$ C) to over $95^{o}$ F ($35^{o}$ C) (James, 2002). This heated stormwater normally becomes runoff, which drains into storm sewers and raises water temperature as it is released into streams, rivers, ponds and lakes. And water temperature affects all aquatic life due to reduction of dissolved oxygen in water. Rapid temperature changes in aquatic ecosystems can be stressful or destructive to aquatic life.

UHIs can produce secondary effects on local meteorology, including the altering of local wind patterns, the development of clouds and fog, the humidity, and the rates of precipitation. The extra heat provided by the UHI leads to greater upward motion, which can induce additional shower and thunderstorm activity.

It is evident that urban areas are always in a risk of increasing heat affects on the natural environment and human social activities. Thus as a developing country, Sri Lanka should aware about these affects to minimise the future impacts. Increasing of the urban population as well as expanding of the urban areas is conspicuous phenomena of the country. High population density of the urban areas makes the high building density which cause to UHI. Thus, as a developing country, it is very necessary to identify such areas to mitigate its impacts on urban environment and especially human health. This research attempts to identify the nature of heating of the urban area of Colombo and Gamapaha districts where highest urbanisation is being taken place.

Main objective of the research was identification of the relationship between Urban Heat Islands and the vegetation as the main factor for UHI formation.Achieving of this task was done through two major steps as identification of UHI areas and Identification of the vegetation cover by calculating Normalised Difference Vegetation Index (NDVI).

There is a high probability to occur UHI in urban areas as mentioned earlier. Thus, study area of the research was selected considering the urbanization of the country. Colombo &Gamapha districts are the highest urbanised districts of Sri Lanka. According to that Colombo &Gampaha districts were selected as the study areas of the research. According to the 2011 census data urban population of the Colombo districts is 1,802,904 of total 2,324,349 populations which represent the 77.6%. There isan urban population of 360,221 from the total 2,304,833 in Gampaha district and percentage is 15.6%. Population density of Colombo district is 3,438 per square kilometer and 1,719 of population density could be identified inGampaha district.

## 2. Methodology

Identification of the relationship between UHIs and vegetation was basically done by using satellite data. Two major steps were followed to archive the objectives. In the first step UHI areas and vegetated areas in Colombo and Gampaha districts were identified and inthe second step relationship wereanalysed between these two. Identification of Urban Heat Islands can be done in two ways. One is measuring air temperature using data of weather station network. Second is the measuring surface temperature using airborne satellite data. First method has high temporal resolution, but spatial resolution is very low. As daily measurements of air temperature are recorded in weather stations, this data represents high temporal resolution. But this temperature is recorded from only one place and it assumes as area temperature. But temperature is varying from one place to another based on different land use and land cover types.Thus, spatial resolution of the weather station data is very low. As an example, Colombo temperature is observed by the weather station located in Department of Meteorology, BauddhalokaMawatha,Colombo 7 and it assumes as air temperature of Colombo districts. But people can feel the variation of air temperature in different land use within the district as well. But remotely sensed temperature measurement from satellites has higher spatial coverage and can be carried on simultaneously. Landsat thermal data can be used effectively to derive the surface temperature of the urban environment. In recent years with the advance of the study on algorithm and the improvement of sensor, remotely sensed data began to be used in the field of urban climate and urban heat island. Thus, this study used Landsat data (L8 OLI/TIRS (Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)) to identify the UHIs in Colombo and Gampaha districts.

### *2.1 Data and software*

The details of data that used for this study is shown in figure 1. Landsat 08 image of 2015 was used to identify the UHIs in study area. And the images in 2001 and 2009 were analyzed to ensure the temperature pattern of the study area.

Table 1: Details of used data for study.

| Data type | Band | Resolution (Meter) | Date Acquired | Scene Center Time (GMT) | Rainfall (Meteorogical data) |
|---|---|---|---|---|---|
| Landsat 05 | Band 06 | 120* (30) | 12/27/2001 | 04:42:35.7185385Z | 0 |
| Landsat 05 | Band 06 | 120* (30) | 2/8/2009 | 04:39:37.4110500Z | 0 |
| Landsat 08 | Band 10 | 100 * (30) | 1/8/2015 | 04:53:58.6959755Z | 0 |

Table2: Bands of Landsat 08 data used for the analysis.

| Band | Wavelength (micrometers) | Resolution (meters) |
|---|---|---|
| **Band 10 - Thermal Infrared (TIRS) 1** | **10.60 - 11.19** | **100 * (30)** |
| **Band 11 - Thermal Infrared (TIRS) 2** | **11.50 - 12.51** | **100 * (30)** |
| **Band 4 - Red** | **0.64 - 0.67** | **30** |
| **Band 5 - Near Infrared (NIR)** | **0.85 - 0.88** | **30** |

*2.2 Data analysis*

Satellite data analysis was done in several steps. There were two main steps as follows.

1. Image Preprocessing and deriving NDVI data
2. Deriving the Land Surface Temperature using thermal band data and NDVI data

Before deriving the LST, following conversions were done to prepossess the images.

01. Convert DN values to TOA Radiance
02. Convert TOA Radiance to Satellite Brightness Temperature
03. Average the Satellite Brightness Temperature (Mean of Band 10 & Band 11)
04. Deriving the Land Surface Emissivity

*Convert DN values to TOA radiance*

OLI and TIRS band data can be converted to TOA (Top Of Atmosphere radiance) spectral radiance using the radiance rescaling factors provided in the metadata file. Following formula used for this purpose that has been introduced by NASA in 2009.

$$L\lambda = MLQ_{cal} + A_L \tag{1}$$

Where;

$L\lambda$= TOA spectral radiance (Watts/ (m2 * srad * µm))

$ML$= Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x, where x is the band number)

$A_L$= Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x, where x is the band number)

$Q_{cal}$= Quantized and calibrated standard product pixel values (DN)

*Convert TOA radiance to satellite brightness temperature*

Landsat 8 OLI/TIRS thermal infrared imagery can beconverted from spectral radiance to brightness temperatureusing following formula (NASA, 2009)

$$T = \frac{K_2}{ln(\frac{K_1}{L_\lambda}+1)} \tag{2}$$

Where;

T= At-satellite brightness temperature (K)

Lλ= TOA spectral radiance (Watts/( m2 * srad * µm))

K1= Band-specific thermal conversion constant from the metadata K1_CONSTANT_BAND_x, where x is the thermal band number)

K2= Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x, where x is the thermal band number)

*Deriving the land surface emissivity*

Land surface emissivity was derived through several steps as follow.

a. Atmospheric Correction for the bands of RED & NIR
b. NDVI calculation
c. Proportion of Vegetation calculation
d. Land Surface Emissivity Calculation

*Atmospheric Correction for the bands of RED & NIR*

DN Values were converted into TOA Reflectance using following equation.

BAND SPECIFIC REFLECTANCE_MULT_BAND X DN VALUES + REFLECTANCE ADD BAND

And then correct the SUN ANGLE as follow.

TOA REFLECTANCE / sin(sun elevation)

*NDVI calculation*

In order to analyse the UHI, Proportion of the vegetation should be analysed. Vegetation cover was extracted from landsat 08 images using NDVI (Normalized Difference Vegetation Index) analysis. Red and Near Infra Red Bands were used for this extraction and following equation (Sobrino et.al. 2004) was followed.

$$NDVI = \frac{R_{NIR} - R_{Red}}{R_{NIR} + R_{Red}} \quad (3)$$

Where;

$R_{NIR=}$ Spectral Reflectance of the Near-Infrared band

$R_{Red=}$ Spectral Reflectance of the Red band

*Proportion of vegetation calculation*

After the calculating NDVI, Proportion of the vegetation was calculated using following equation (Sobrino et.al. 2004) to use for the deriving Land Surface Emissivity.

$$P_V = (NDVI–NDVImin/NDVImax–NDVImin)^2 \quad (4)$$

*Land surface emissivity calculation*

Land Surface Emissivity is very important to analyze the Land Surface Temperature and it was calculated using following formula that has been introduced by Sobrino in 2004.

$$E = 0.004P_V + 0.986 \quad (5)$$

*Deriving the land surface temperature*

Finally Land Surface Temperature was derived by following equation (Weng, 2005) to identify the Urban Heat Island in Colombo and Gampaha District.

$$BT / 1 + W\times(BT / P)\times In(e) \quad (6)$$

Where;

BT = At Satellite Temperature (Satellite Brightness Temperature)
W = Wavelength of emitted radiance (11.5Um)
P = h*c/s (1.438*10^-2 m K)
H = Planck's constant (6.626*10^-34 Js)
S = Boltzmann Constant (1.38 * 10^-23 J/K)
C=Velocity of light (2.998 * 10^8 m/s)

## 3. Results and Discussion

Based on the results of temperature analysis, UHI temperature was decided. The total land area of Western Province is 3693.12km$^2$. According to the results, the area of 2, 949km$^2$ shows the temperature less than 25$^o$C. It represents the 79.8% of total land area of the province. According to the United State Environmental Protection Agency, UHI can be identified as the area where 1-3$^o$C temperature higher than the surrounding. Thus, temperature of the UHI was decided as 27$^o$C (at 10.22 am) that represents the 2$^o$C higher than normal.

### *3.1 Land surface temperature in Colombo and Gampaha districts*

According to the research output, it was obvious that land surface temperature in Colombo and Gampaha Districts directly relates with the urbanization pattern. Figure 05 shows the spatial distribution of land surface temperature of Colombo and Gamapaha Districts in the years 2009 and 2015.Table 3 shows the descriptive statistics of the land surface temperature over the study area in 2001, 2009 and 2015. The minimum temperature was 21.01$^o$ C in the year 2001 and then it was increasing in 2009 up to 23.37$^o$ C then in 2015 it has been decreased a little as 23.05$^o$ C. However, about 2$^o$ C of temperature increase of minimum temperature can be identified by comparing to the year 2001. Decrease of maximum temperature can be identified with the details of Table 02 as 35.49$^o$ C in 2001, 35.96 in the year 2009, and it was the 34.003$^o$ C in 2015. In 2009 temperature shows the increase of maximum temperature and but it was decreased about 1.95$^o$ C in 2015. Especially it should be noted, that temporal trend of temperature variation cannot be identified with this methodology, because continuous temperature data should be analyzed to identify such variations. Thus, this research focuses only about the spatial trend of the land surface temperature distribution in study area.

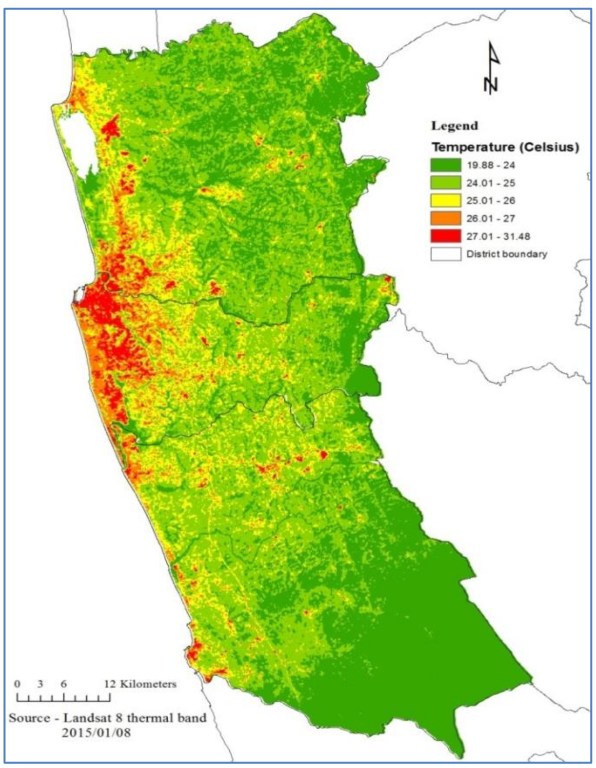


Figure 4: Temperature distribution in WP.

Figure 5 shows the temperature distribution of study area based on five classes as 21.01-24, 24.01-26, 26.01-27, 27.01-28 and 28.01 and above. Maximum temperature class was classified with considering minimum temperature reported, and maximum temperature class was classified with considering normal average temperature of the study area. Normal average temperature of Colombo and Gampaha districts is $27^{o}$ C. Thus Figure 5 shows the high temperature areas where higher than average in orange and red colors.

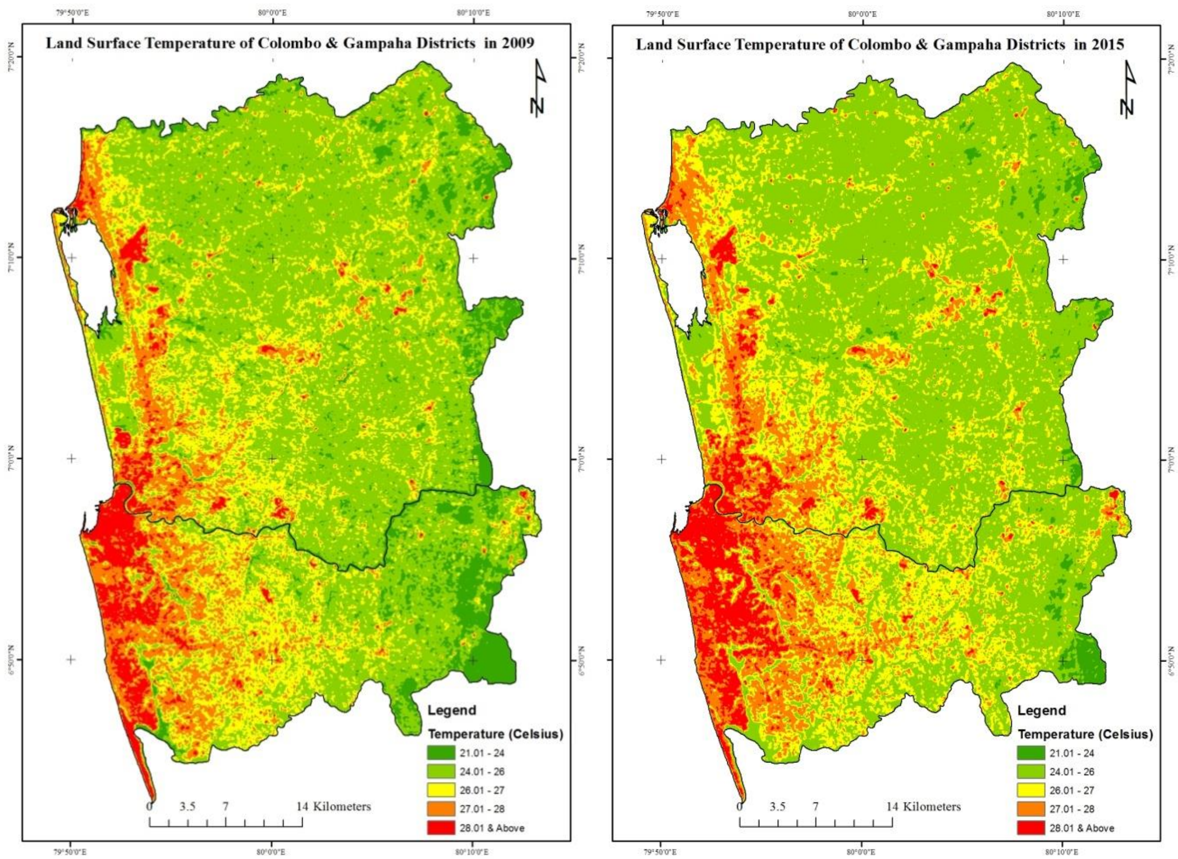


Figure 5:Land Surface Temperature Distribution in 2009 & 2015 of study area.

Table 3: Land Surface Temperature of the study area.

| Year | Temperature (Celsius) | | |
|---|---|---|---|
| | Minimum | Maximum | Mean |
| 2001 | 21.01 | 35.49 | 25.01 |
| 2009 | 23.37 | 35.96 | 28.75 |
| 2015 | 23.05 | 34.003 | 27.66 |

This study introduced the three types of areas in Colombo &Gampaha districts as follows.

1. The areas in the temperature more than average (>$27.01^{o}$ C)
2. Vulnerable areas of Urban Heat Island affect, where the temperature more than $31^{o}$ C.
3. Urban Heat Island areas, where the temperature more than $32^{o}$ C.

Figure 5 shows the first type of areas very clearly. As well as figure 6 shows the relationship between land surface temperature and road network. Roads are normally covered with tar that caused to make low albedo as well as building density of either side of the roads is higher than the other areas. Thus, high temperature condition of these areas can be identified by comparing with surrounding.Figure 7 shows the relationship between temperature and local authorities. There are three different local authorities as Municipal Councils (MC), Urban Councils (UC) and PradeshiyaSabha (PS) that have been classified considering the urbanization process and population. Urbanized areas represent the MC & UC where has high building density due to dense population. Thus, Most of the UHIs are located within these areas. This pattern shows the positive correlation with urban process with developing UHIs.

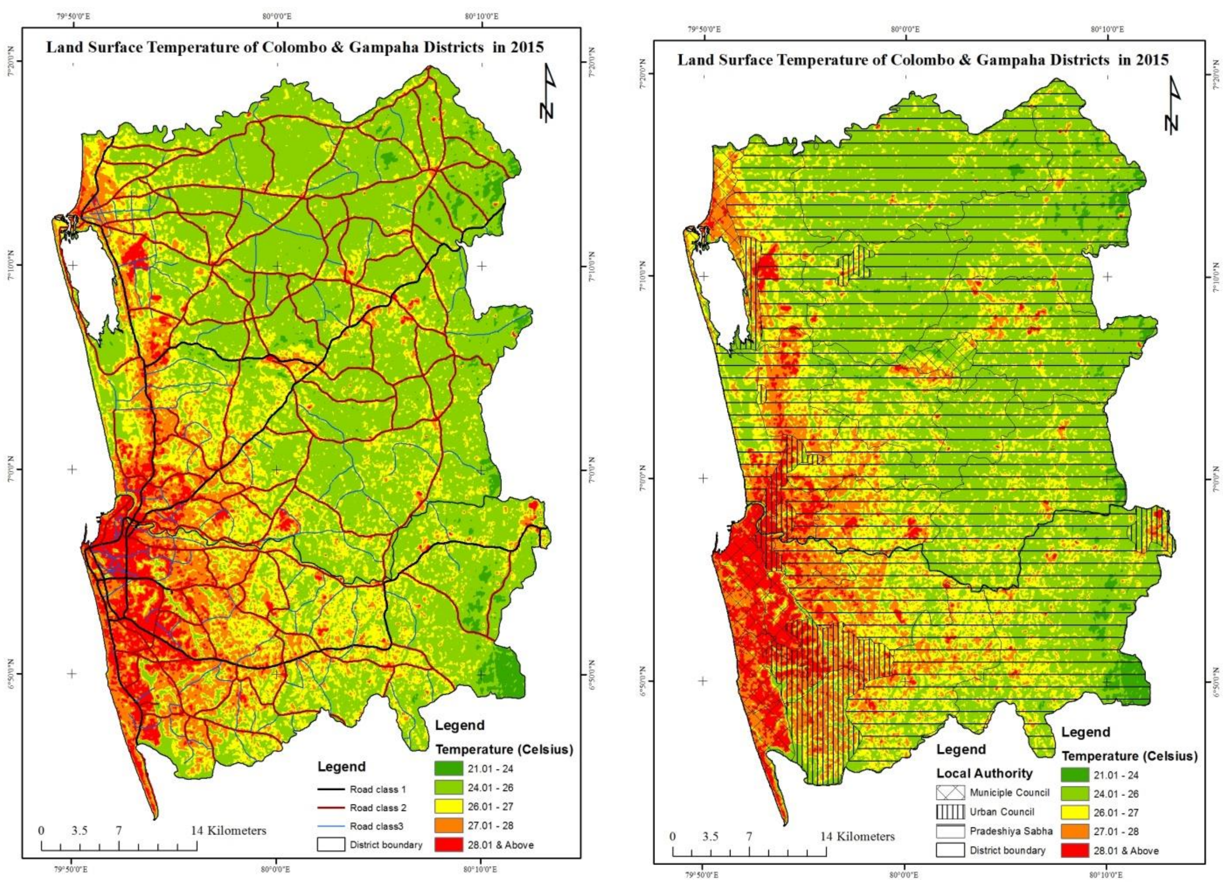


Figure 6: LST with Road network.

NDVI index has long been used to monitor the vegetation and its changes in entire earth. Resulted NDVI values classified into five groups as shown in figure 08 based on the results and literature findings. Negative values of NDVI represent the water bodies and this can be changed up to 0.003 due to pollution or sediments of the water bodies. Resulted NDVI map shows the water bodies in the range from -0.125 to 0.0028.The values of 0-0.1 represent the open and impermeable surfaces such as rocks, sand, snow or densely built up areas where covered by concrete or tar.

According to that, result of the NDVI calculation shows the densely built up areas in the range from 0.0029- 0.1. The values of 0.1-0.2 also represent the open areas such as soil or built up areas. NDVI map shows the built-up areas in the values range from 0.1 to 0.2. NDVI values from 0.2 to 0.3 represent the vegetated areas such as shrubs or grasslands while 0.3 to 0.8 represent the dense vegetation. Maximum NDVI value of the result is 0.43.Figure 9 and 10 show the distribution of vegetation and temperature in study area. Figure 09 shows the vegetation in green color. Dark green shows dense vegetation while light green shows sparse vegetation. Purple color shows the built-up areas and red color shows the densely built up areas. Blue color represents the water bodies in study area.

| NDVI range | Surface properties |
|---|---|
| **Negative values** | **Lakes, rivers, and ocean** |
| **0-0.1** | **Rock/Sand/Snow/built up areas** |
| **0.1-0.2** | **Soils/ built up areas** |
| **0.2 - 0.3** | **Shrubs/Grasslands/Bare soils** |
| **0.3 - 0.8** | **Dense vegetation** |

Figure 08 – Surface properties of NDVI values.

Figure 10illustrates the spatial variation of temperature. It is clearly obvious that even in the same climatic zone temperature is distinct. In the map, red color shows the high temperature areas where temperature is higher than 27$^{o}$C. Orange color represents the areas where temperature between 25.01-27$^{o}$C. Yellow color shows temperature ranges from 25.01 to 26$^{o}$C while light green color is representing temperature range from 24.01 to 25$^{o}$C. Dark green color shows the areas where temperature is comparatively very low, less than 24$^{o}$C.

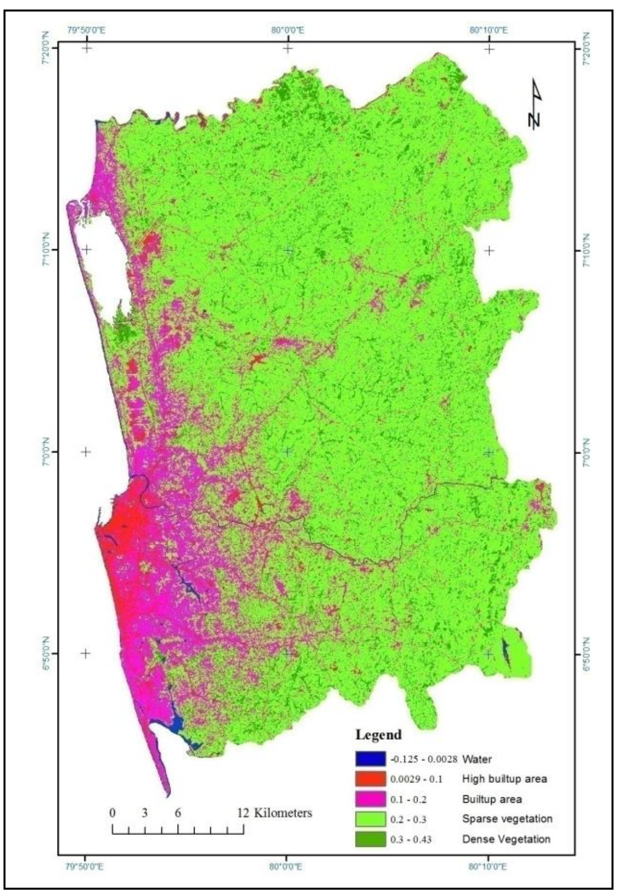


Figure 9: Distribution of Vegetation.

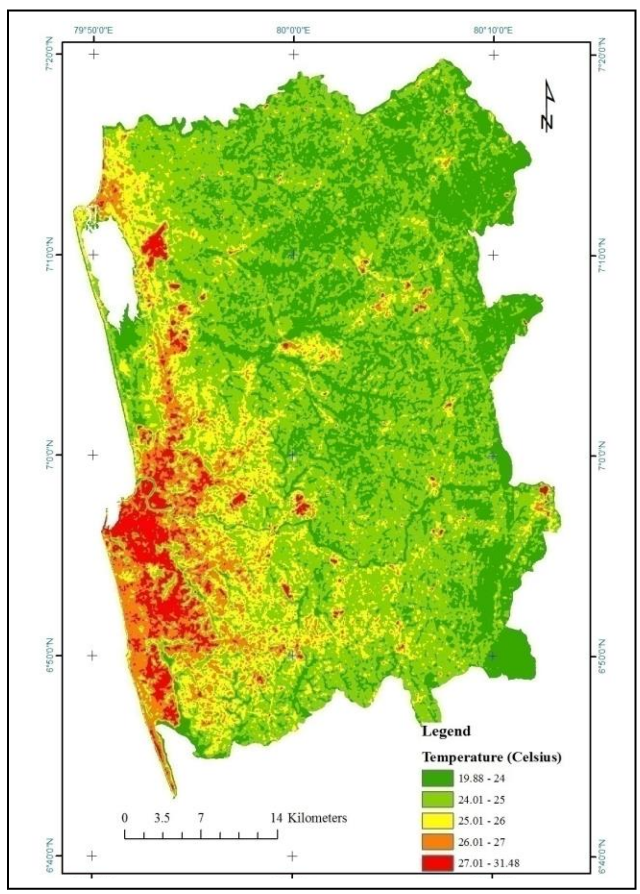


Figure 10: Distribution of Temperature.

Figure 9 and 10 clearly shows the relationship between vegetation and the temperature. Built up areas or non-vegetated areas directly relate with the high temperature areas. Densely built up areas can be identified as Urban Heat Islands according to the temperature distribution map. Road network of the area is also representing the high temperature due to lack of vegetation. But some non-vegetated and built up areas represent the low temperature condition in coastal areas due to local wind process (sea breeze).And vegetated areas in vegetation map clearly relate with the low temperature areas in temperature map. Water bodies in the districts are also show the low temperature condition. It is clearly obvious that transpiration of water bodies and evapotranspiration of vegetated areas are the major processes that relate with the regional distinct spatial pattern of the temperature. This relationship could be verified by observing Google images of particular areas.

Figure 11 represent the NDVI, temperature and actual ground images of Sothern part of Negombo Lagoon. This combination clearly shows the relationship between vegetation and the temperature. Vegetated and marsh areas of Google images represent the vegetation in NDVI map and low temperature in temperature map. It is a result of evapotranspiration process of the vegetation that effect to cool the air naturally. But built up areas had blocked this process as removing vegetation cover and cover that area by impermeable surfaces such as concrete and tar.

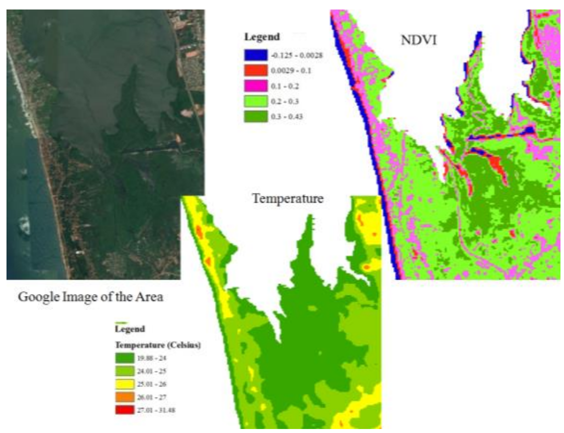


Figure 11 – Sothern part of Negombo Lagoon

Figure 11: NDVI, Temperature and actual ground images of Sothern part of Negombo Lagoon.

Figure 12, 13, 14 and 15 clearly show the relationship between vegetation and the temperature. Figure 13 represent the Sri Lanka parliament and its surrounding. According to the temperature distribution map parliament area is also a UHI area. Most of the parts of parliament complex had covered by concrete. This situation disturbs the evaporation process that water release from soil. As well as less vegetation result the low transpiration rate. These reasons have caused to make the parliament complex into urban heat island. Colombo Pettah area in figure 12 had been identified as the largest UHI in Sri Lanka where very less vegetation cover has. Most of the parts could be identified as densely built up areas. Figure 15 shows the vegetated areas as well as urbanized areas in Gampaha city. This image is a good indicator to identify the relationship between vegetation and temperature. Figure 14 also represent how vegetation causes to decrease the regional temperature.

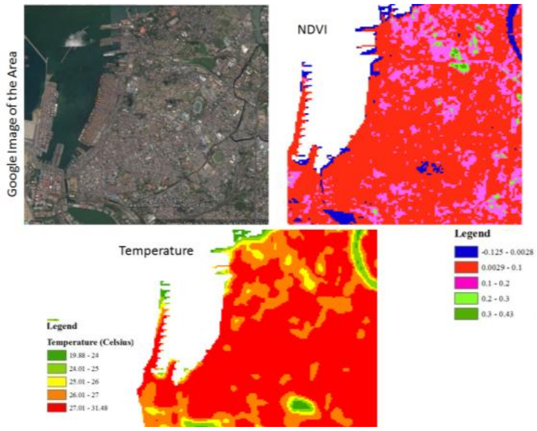


Figure 12: Colombo

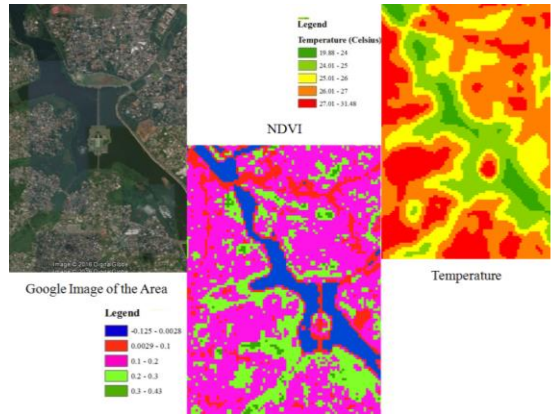


Figure 13: Sri Lanka Parliament and its surrounding

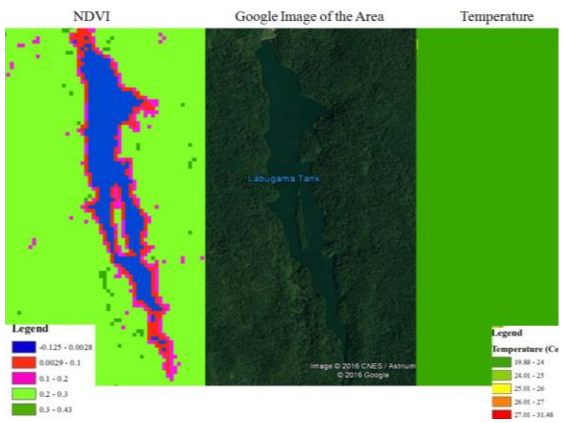


Figure 14: Labugama Tank and its surrounding

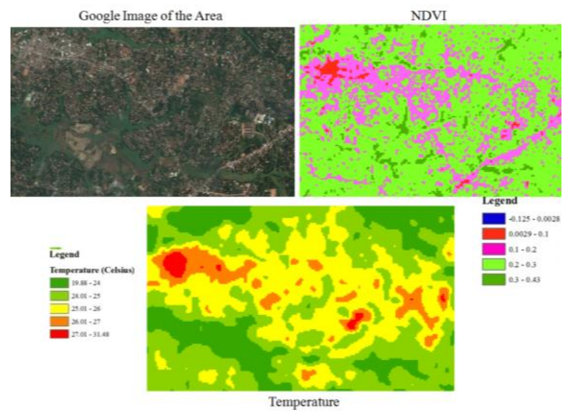


Figure 15: Gampaha town and its surrounding

Table 4 shows the relationship between land extent of temperature and NDVI. This is also one of important evidence that confirm the relationship between vegetation and temperature. As shown in figure 13, there is a strong linearly negative correlation with correlation coefficient value of -0.742.

Table 4: Land extent of different NDVI and temperature ranges.

| NDVI range | Area (Sqkm) | Temperature range | Area (Sqkm) |
|---|---|---|---|
| less than 0.1 (including water) | 78.8 | more than 27°C | 74.12 |
| 0.1-0.2 | 333.04 | 25-27 | 464.95 |
| 0.3-0.4 | 1471.1 | less than 25°C | 1529 |

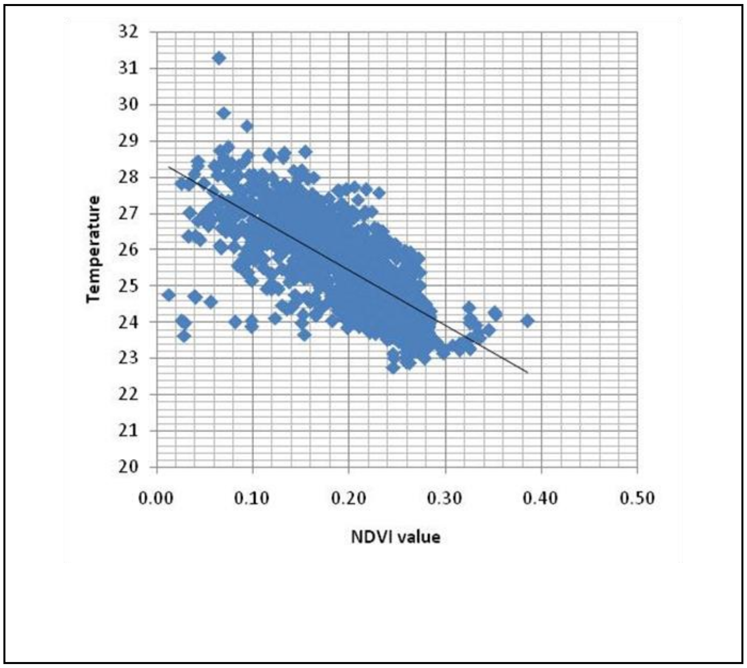


Figure 16:Correlation of temperature & NDVI.

*Vulnerable areas for UHI affects*

Figure 17 shows the vulnerable areas of Urban Heat Islands affects, where the temperature more than 31$^{o}$ C. As well as Table 5 shows the land extent of each class in the years of 2001, 2009 and 2015. According to that, it is obvious, that land area in high temperature class is gradually increasing.

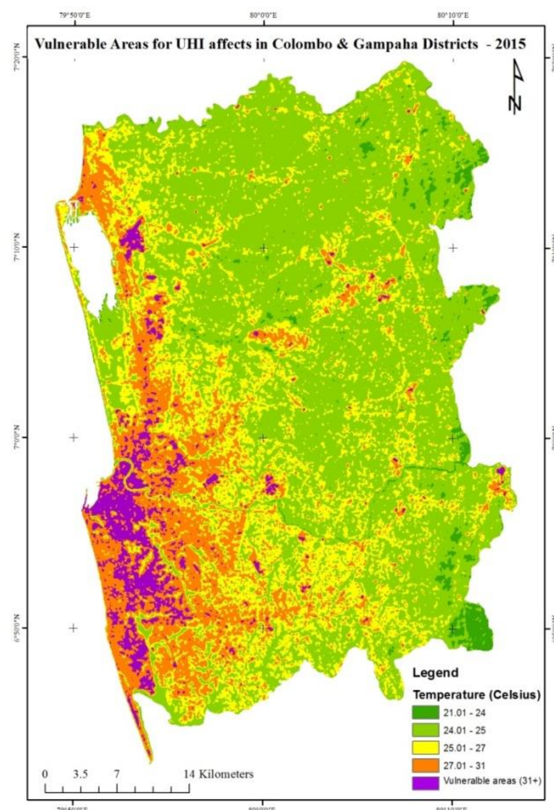


Figure 17: Vulnerable areas for UHI affects in of Colombo and Gamapaha districts

As well as land area of minimum temperature class is decreasing. Figure 18 shows this variation is very clearly. According to that, in 2001 the land areas above 31° C temperature was 54.71 Sqkm and it was increased up to 87.96 Sqkm in 2009 and then 2015 that value was 121.01 Sqkm. As well as decrease of land area in minimum temperature (21-24° C & 24.01-25° C) ranges can be clearly identified in the study area.

Table5: Land extent of each temperature class.

| Temperature (Celsius) | Area (Sqkm) | | | | | |
|---|---|---|---|---|---|---|
| | Year 2001 | % | Year 2009 | % | Year 2015 | % |
| 21-24 | 281.91 | 14 | 174.51 | 8 | 41.42 | 2 |
| 24-26 | 1284.83 | 62 | 1088.26 | 53 | 1112.6 | 54 |
| 26-27 | 291.21 | 14 | 470.33 | 23 | 497.62 | 24 |
| 27-31 | 150.435 | 7 | 242.37 | 12 | 290.816 | 14 |
| 31< | 54.71 | 3 | 87.96 | 4 | 121.01 | 6 |
| | 2063.10 | 100 | 2063.43 | 100 | 2063.47 | 100 |

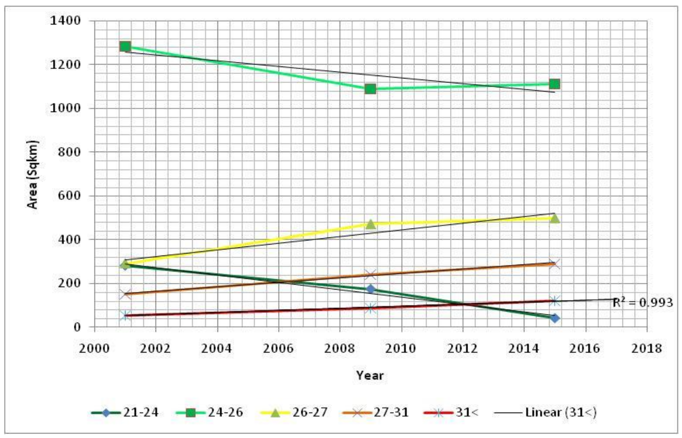


Figure 18: Land area variation of each temperature class in year 2001,2009 and 2010.

27 local authorities of Colombo andGampaha districts were identified where vulnerable areas are located. As well as 493 GramaNiladhari Divisions were recognised as vulnerable for UHI affects from those 27 local authorities. Table 06 shows the descriptive statistics of identified vulnerable areas and figure 19 shows the spatial distribution of those UHI areas. According to that, all Municipal Councils (MC) and Urban Councils have vulnerable areas of UHI. As well as 11 PradeshiyaSabha were also selected as vulnerable. Most of those areas were recognized as industrial estates while ground verification throughGoogle earth images. Figure 20 shows the google images of numbered vulnerable places of figure 19, which located in pradeshiyasabhas.

The total of GramaNiladhari Divisions of Colombo MC, were identified as vulnerable for UHI affects. The total area of the Colombo MC is 40.56Sqkm and it is the highest urbanized local authority of the country. 15% of total urban population is living in Colombo MC area. According to the census statistics in 2012, there are 561,314 population and population density is 13,364 per Sqkm in this MC. Thus building density and industrial, commercial activities are higher than the other areas. As well as daily moving population of this MC is also higher than the other areas and this causes to occur high vehicle traffic and high air pollution. Thus at present 64% of the Colombo MC area has been vulnerable for the UHI affects. As well as more than 50% of the total areas of Sri Jayewardenpurakotte and Dehiwala-Mt-Lavinia MC areas had been selected as vulnerable. 71% of Kolonnawa UC area is also vulnerable, but total land area of this, is very less compared with other local authorities.

Table6: Vulnerable Local Authorities.

| | Local Authority | No. of Vulnerable GNDs | LA Area Total | Vulnerable area for UHI affects (Sqkm) | % from Total LA Area |
|---|---|---|---|---|---|
| 1 | Kolonnawa UC | 14 | 5.39 | 3.877 | 71.92 |
| 2 | Colombo MC | 55 | 40.56 | 26.159 | 64.50 |
| 3 | Sri Jayawardanapura Kotte MC | 20 | 16.50 | 10.0562 | 60.95 |
| 4 | Dehiwala_Mt.Lavinia MC | 28 | 21.14 | 11.0525 | 52.29 |
| 5 | Peliyagoda UC | 7 | 7.54 | 3.33897 | 44.30 |
| 6 | Wattala - Mabola UC | 5 | 12.41 | 5.28098 | 42.55 |
| 7 | Moratuwa MC | 42 | 19.59 | 8.22501 | 41.98 |
| 8 | Kelaniya PS | 30 | 13.26 | 4.9669 | 37.46 |
| 9 | Borelesgamuwa UC | 17 | 11.82 | 3.23529 | 27.37 |
| 10 | Maharagama UC | 36 | 37.08 | 9.30347 | 25.09 |
| 11 | Ja Ela UC | 7 | 1.36 | 0.312652 | 22.99 |
| 12 | Kotikawatta_Mulleriyawa PS | 29 | 22.03 | 3.39833 | 15.42 |
| 13 | Wattala PS | 21 | 42.54 | 3.05522 | 7.18 |
| 14 | Seethawakapura UC | 4 | 12.89 | 0.705303 | 5.47 |
| 15 | Negombo MC | 17 | 27.64 | 1.44277 | 5.22 |
| 16 | Biyagama PS | 20 | 60.67 | 3.14269 | 5.18 |
| 17 | Kaduwela MC | 24 | 85.73 | 4.09048 | 4.77 |
| 18 | Katana PS | 11 | 93.58 | 4.36402 | 4.66 |
| 19 | Katunayaka Seeduwa UC | 7 | 13.19 | 0.559664 | 4.24 |
| 20 | Ja Ela PS | 27 | 59.55 | 4.78 | 1.27 |
| 21 | Kesbewa UC | 11 | 50.50 | 0.759233 | 1.50 |
| 22 | Mahara PS | 20 | 95.49 | 1.36254 | 1.43 |
| 23 | Homagama PS | 13 | 117.58 | 1.20363 | 1.02 |
| 24 | Attanagalla PS | 22 | 151.09 | 1.05337 | 0.70 |
| 25 | Minuwangoda PS | 2 | 123.24 | 0.175896 | 0.14 |
| 26 | Gampaha PS | 1 | 79.84 | 0.080703 | 0.10 |
| 27 | Gampaha MC | 3 | 17.98 | 0.003059 | 0.02 |

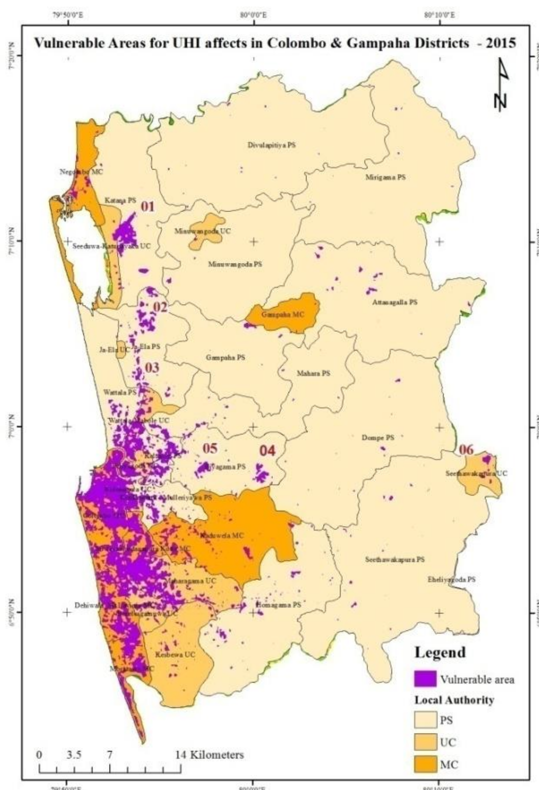


Figure 19: Vulnerable LA areas.

Figure 20: Google images of numbered places in figure 09.

*UHI areas in Colombo &Gampaha districts*

Figurre22 shows UHI areas where the temperature greater than $32^{o}$ C in study area. These areas can be identified as high temperature areas compared with surroundings. According to that 4 major Urban Heat Islands were identified as follow.

01. Colombo MC area
02. Katunayake airport area
03. South part of Dehiwala-Mt.Lavinia MC area
04. North part of Moratuwa MC area
05. Avissawella Industrial park area of Sithawakapura UC

Especially Colombo, Pettah area can be identified as fully built up and higher traffic area. Because, this area is usually identified as major commercial city of Sri Lanka. It is the center of the urbanization of the whole country. As far as urbanization pattern of Sri Lanka is concerned, it was clearly identified, that whole surrounding parts of the Colombo city is gradually converting to urban areas. This matter was the major reason to establish the Western Province Mega-police project which whole province make developed as a mega city. But it is very important to pay policy makers' attention for this high temperature condition which directly affected on human health, environment as well as economy.

Katunayake Airport area is the $2^{nd}$highest UHIs, identified with this study. It is also represent the high temperature compared to the surrounding from the year 2001 to present. South part of Dehiwala-Mt.Lavinia MC and north part of Moratuwa UC are also identified as UHIs. High building density and the population density can be identified here. As well as Rathmalana Airport is located in this area. Avissawella Industrial park is also recognized as UHI, because of high surface temperature compared with surrounding. Thus mitigation activities should be introduced to here for protection of environment and human health.

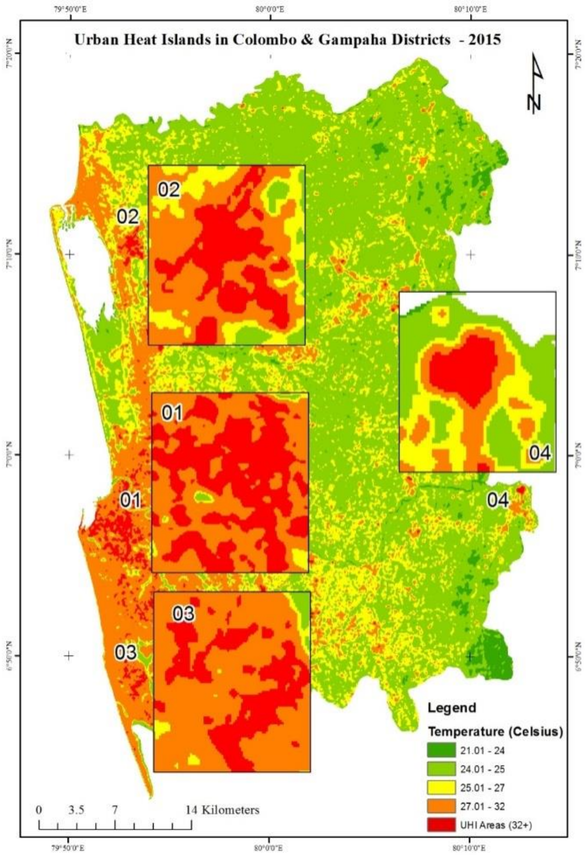


Figure 22: Urban Heat Islands in Colombo &Gampaha Districts.

## 4. Conclusions

Area of 74.12 Sqkm in Colombo &Gampha districts was identified as Urban Heat Islands.High temperature at non-vegetated or built up areas and low temperature at vegetated or water areas could be noted very clearly.This is probably due to the ecological function of vegetation that lay down the surface temperature from high evapotranspiration.Research output is useful for policy-makers and planners of development projects such as Western province Megapolis project.General public can understand the urban heat island effects and importance of vegetation cover to mitigate such impacts with this output. Figure 23 shows the activities that helpful to mitigate the UHI impacts.

Figure 13: Mitigation activities.

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