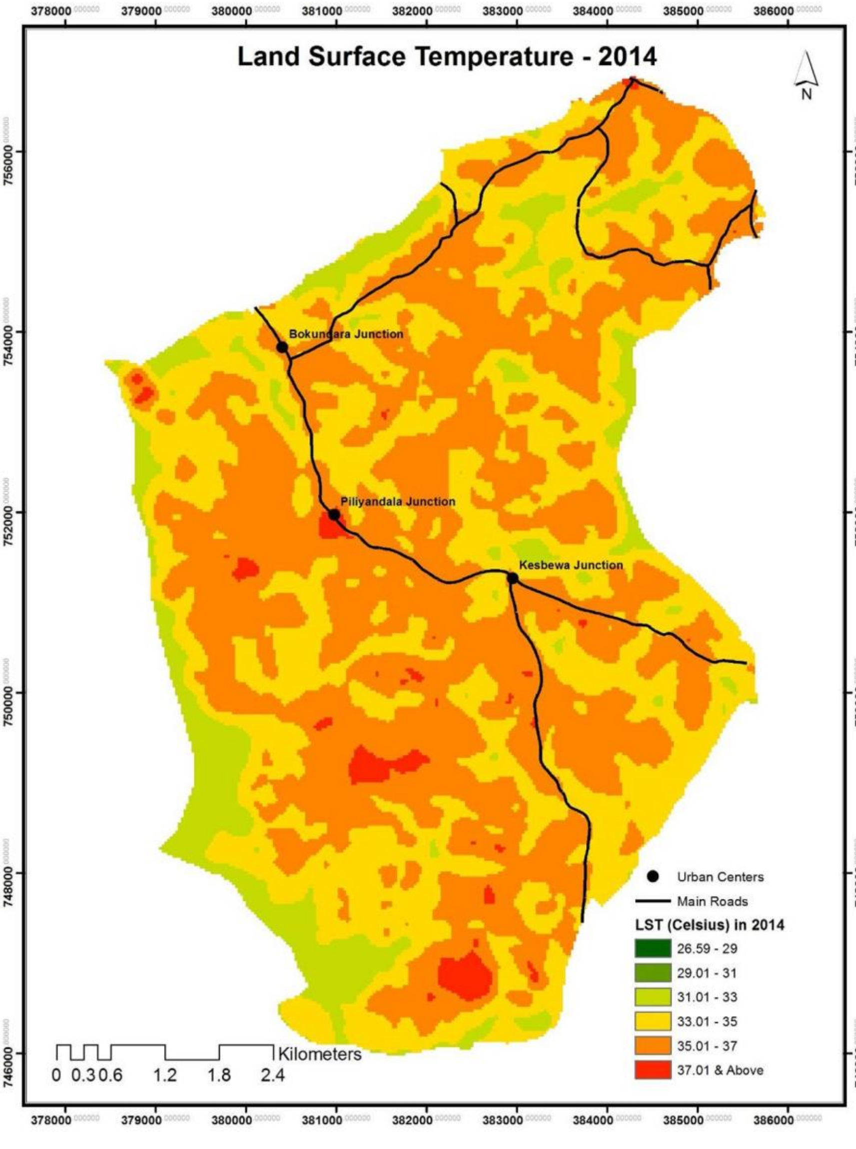
LAND SURFACE TEMPERATURE VARIATIONS IN KESBEWA URBAN COUNCIL AREA, SRI LANKA



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Contents

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Preparation of this report involved a team of researchers from the University of Colombo and the University of Rajarata in Sri Lanka, including Prof. L. Manawadu (Department of Geography, University of Colombo); Prof. YM. Wickramasinghe (Department of Agricultural Systems, University of Rajarata); Dr. Sudeera Ranwala (Department of Plant Science, University of Colombo); Dr. MT. Mahees (Department of Sociology, University of Colombo); Mr. Manjula Ranagalage (Department of Social Sciences, University of Rajarata); Mr. ENC Perera, IHRA (University of Colombo). Valuable comments and inputs were received from the peer reviewer, Francisco Escobedo. RUAF Foundation, through Marielle Dubbeling, coordinated the research activities undertaken.

Acronyms and abbreviations

^{0}C	:	Degree Celsius
ETM+	:	Enhance Thematic Mapper
KUC	:	Kesbewa Urban Council
LST	:	Land Surface Temperature
LU/LC	:	Land use and Land cover
UHI	:	Urban Heat Island
UPAF	:	Urban and Peri Urban Agriculture and Forestry

1. Introduction

Recent climatological studies from different disciplines across the world have proved that the surface temperature of urban areas have increased relative to neighbouring vegetated areas. Induced primarily by urbanisation and global warming, this trend is experienced not only in industrialised countries but also in developing countries (Doick & Hutchings, 2013).

The report of Initial National Communication under the United Nations Framework Convention on Climate Changes (http://unfccc.int/, 2010) already indicated such trend of increasing temperature in developing countries. Statistical analyses temperature, rainfall and other meteorological data collected by the Department of Meteorology in Sri Lanka over a period of more than 100 years show an increasing trend in the mean annual air temperature across the entire island, particularly during the period 1961 -1990, and this increase was found to be approximately 0.16^{0}C per decade (http://unfccc.int/, 2010).

Rapid urbanisation has led to a conversion of rural areas into built-up areas and loss of green spaces in cities. These changes in land use/cover (LU/LC) concern loss of agricultural and forest lands, loss of vacant areas and increase in area of impermeable surfaces. This increased area in building, other urban activities and impermeable cover has contributed to increased urban heat island (UHI) effects in urban centers (Ukwattage and Dayawansa, 2012). An UHI is a climatic phenomenon in which urban areas have higher air temperature than the surroundings rural areas (Figure 1). Specifically, high(er) energy consumption for human and industrial uses and increased land surface coverage by building and pavements with high heat reflection capacities cause the UHI phenomena (Buyadi et al, 2012). The increase in built-up areas is similar to increased UHI trends, thus indirectly confirming the relationship between urbanisation and increased temperatures (Ukwattage and Dayawansa, 2012).

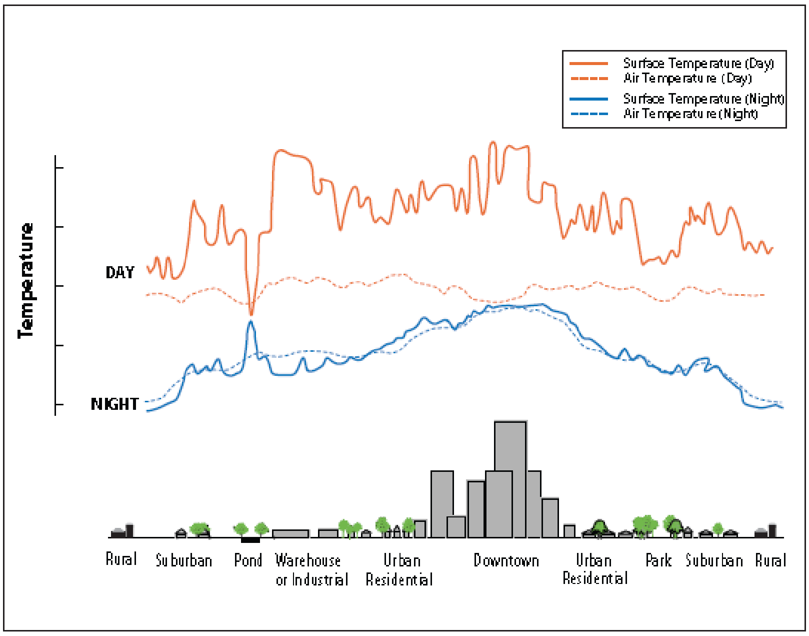


Figure 1: Surface and Air Temperatures relationship. Source: http://www.epa.gov, 2014

Surface temperatures have an influence on air temperatures (http://www.epa.gov, 2014). As warm and cold air mix within the atmosphere, air temperatures typically vary less than surface temperatures across an area (see Figure 1).

In rural areas, vegetation and open land areas typically dominate the landscape. Trees and vegetation provide shade, which helps lower surface temperatures. Vegetation also reduces air temperature through evapotranspiration, in which plants release water to the surrounding air, dissipating ambient heat. In contrast, urban areas are characterised by dry, impermeable surfaces, such as building roofs, sidewalks, roads and parking lots. These ground covers results in less shade and moisture to keep urban surfaces cool. Built up areas also evaporate less water (Figure 2), thus also contributing to elevated surface and air temperatures (http://www.epa.gov, 2014).

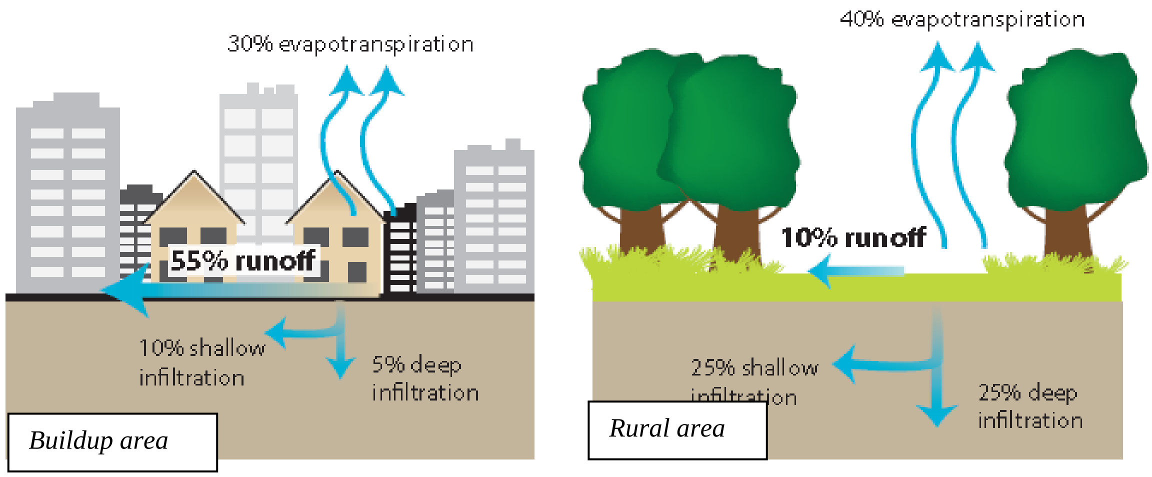


Figure 2: Evapotranspiration effects on land use and surface temperature. Source: http://www.epa.gov,

One promising way of studying urban surface temperature is using airborne technology or satellite remote sensing. Estimation of Land Surface Temperature (LST) from remotely sensed data is common and typically used in studies of evapotranspiration and desertification processes (Streutker, 2003). The wide use of LST for environmental studies, have made remote sensing of LST an important academic topic during the last two decades. Indeed, one of the most important parameters in all surface-atmosphere interactions and energy fluxes between the ground and the atmosphere is LST. Additionally, LSTs are sensitive to vegetation and soil moisture, hence this relationship can be used to detect Land use/Land cover (LU/LC) changes such as urbanisation, desertification etc. The knowledge of surface temperature is important to a range of issues and themes in the environmental sciences such as urban climatology, global environmental change, and human-environment interactions (Buyadi et al, 2012). Various studies have been carried out to investigate LST using vegetation abundance metrics (Buyadi et al, 2012; Streutker, 2003).

Some major effects of the atmosphere on remote sensing data are light absorption, upward atmospheric emission, and the downward atmospheric irradiance reflected from the surface (Mallick et al, 2008). Land surface temperature can therefore provide important information about the earth's surface physical properties and climates which play a role in many environmental processes

(Dousset and Gourmelon 2003). Many studies have measured urban air temperature, using land based observation stations, but remote sensing provides an alternative to land-based measurement methods. The advantages of using remotely sensed data are their global coverage, multi- resolution and temporal availability and consistent measurements of earth surface conditions (Owen, Carlson & Gillies 1998). Specifically, thermal infrared (TIR) sensors can obtain quantitative information of surface temperature across multiple LU/LC categories. Available thermal infrared sensors include the Geostationary Operational Environmental Satellite (GOES) with 4-km resolution in the thermal infrared, the NOAA-Advanced Very High Resolution Radiometer (AVHRR), Terra and Aqua-Moderate Resolution Imaging Spectro radiometer (MODIS) with 1-km spatial resolution. The high resolution data from the Terra-Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) have a 90-m resolution, while the Landsat-7 Enhanced Thematic Mapper (ETM+) has a 60-m resolution in thermal region (Mallick et al, 2008). Both Landsat 5 TM and Landsat 7 ETM+ have been widely used to monitor the land use changes, and to model the biophysical characteristics of the earth surfaces (Mallick et al, 2008).

There are many studies that have documented the impact of urbanisation and green vegetation on climate and several of them focused mainly on UHI effects in the central core of urban areas (Manawadu and Liyanage, 2008). Measurement of change in UHI at regional levels can lead to understanding spatial and temporal patterns of UHI. However, in cities such as Colombo, the largest and capital city in Sri Lanka, there is only one meteorological observatory which is located near the southeast boundary of the city. This makes any analyses of spatial patterns of temperature in the inner area as well as the periphery of the city difficult (Manawadu and Liyanage, 2008). In this case, using remotely sensed data can provide a means to better understand the effects of urbanisation on LSTs.

The aim of this study is to measure Land Surface Temperature (LST) variation in the Kesbewa Urban Council (KUC), Sri Lanka using thermal infrared (TIR) images to better assess the role of various forms of green spaces, specifically urban and peri-urban agriculture and forestry (UPAF), on UHI. Kesbewa is located within the Colombo District at 21 km from the Colombo. The specific objectives are to:

1. Estimate LST differences between UPAF areas and dense, highly built areas comparing data from 2001 to 2014, and
2. Map the spatial variations in LSTs across the KUC area.

This type of study will contribute to better informing urban planning and land use management needs based on improved urban design and human comfort, in developing countries.

2. Data and Methods

2.1 Study area

The study area is the Kesbewa Urban Council (KUC) that encompasses 50.39 km2 in the Colombo district located in the Western province in Sri Lanka (Figure 3). KUC lies on the Colombo-Horana main road about 20km away from the commercial capital of Sri Lanka and is part of the Colombo urban fringe that has been rapidly increasing in population. It is also characterised by high and rapid conversion of agricultural to urban LU/LCs. The KUC is located in the Low country Wet zone which is classified based on the altitude from the mean sea level and annual rainfall (Department of Meteorology, Sri Lanka). The KUC study area is characterised by four rainy seasons; the first Inter-monsoon period from March to April, the Southwest Monsoon period from May to September, the Second inter-monsoon period from October and November and the Northeast monsoon period from December to February (Figure 4; Department of Meteorology, Sri Lanka). During the Southwest monsoon period, the area receives more than 500 mm rainfall, while during the second inter-monsoon and the northeast monsoon periods the area receives more than 200mm average rainfall in some months (Department of Meteorology, Sri Lanka).

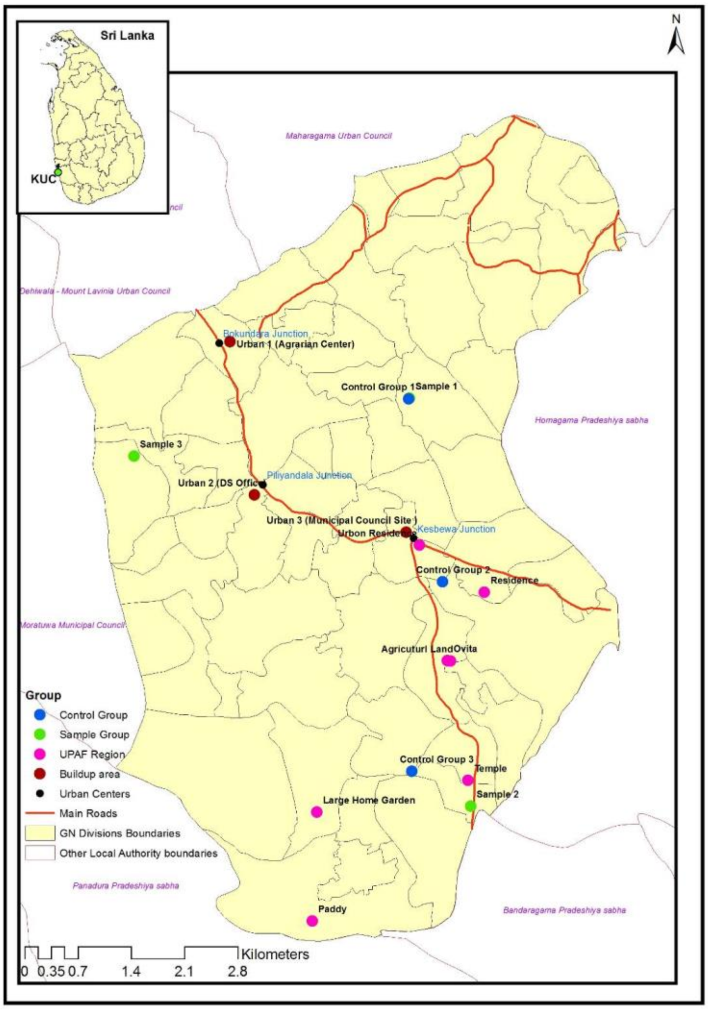


Figure 3: The 2013 Kesbewa Urban Council study area in Sri Lanka.

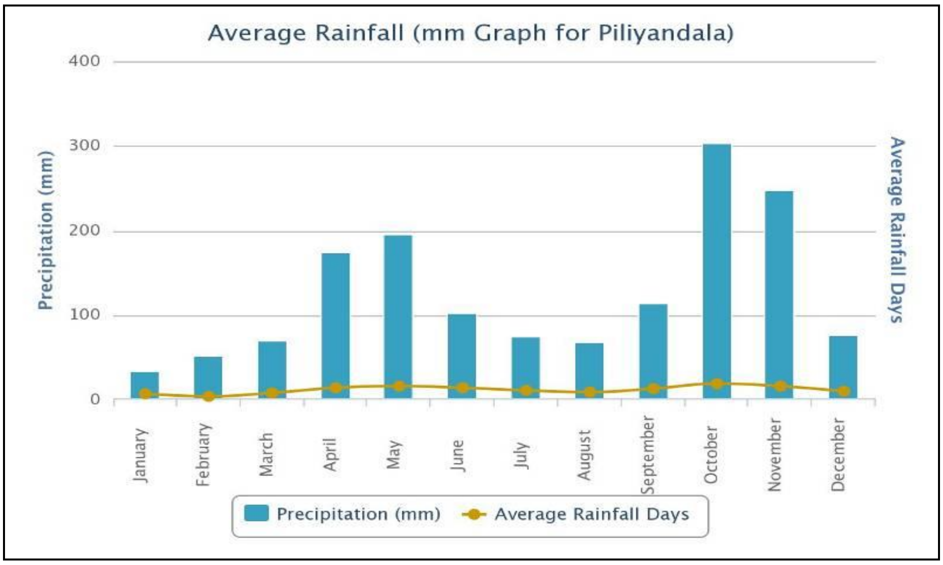


Figure 4: Average rainfall of Kesbewa Urban Council (Piliyandala area in the KUC urban core), Sri Lanka from 2008 – 2013. Source: World Weather Online, 02.12.2013

The average air temperature of the KUC area for last 5 years (2008 to 2013) is 28.05 ^{0}C, ranging from 31.33^{0}C (Maximum) temperature to 24.50^{0}C (Minimum) with some significant deviations. During the Southwest Monsoon period (May to September) average temperature is relatively low when compared with the 1st inter monsoon period and the northeast monsoon period (Figure 5). The hottest season of the KUC is January to March. During 2008 to 2013, the KUC area has shown an increasing trend in air temperature (Figure 6), which might be a result of rapid urbanisation in the Colombo and KUC areas.

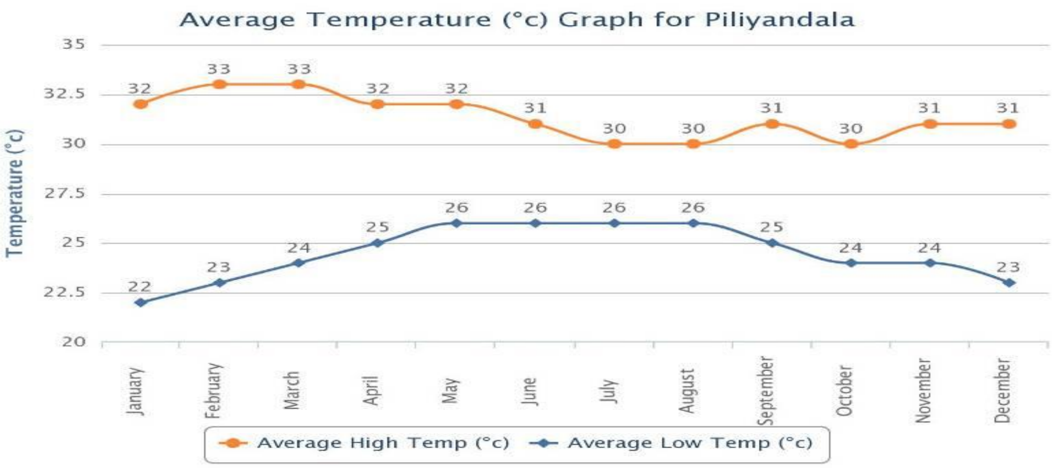


Figure 5 Average temperature ranges for the Kesbewa Urban Council study area.

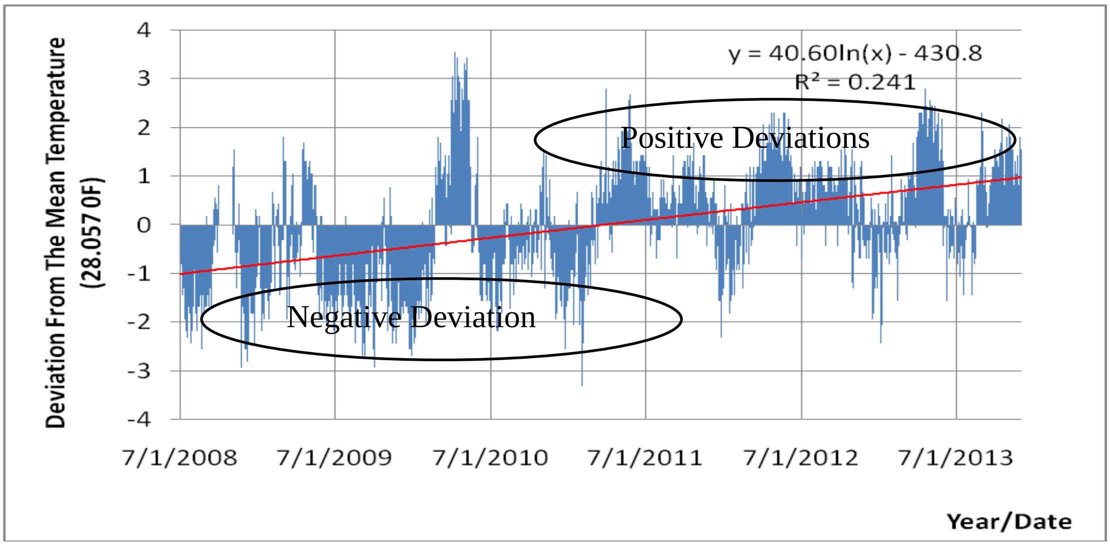


Figure 6: Air Temperature variation in Piliyandala City area, Sri Lanka. Source: www.worldweather.com/ 2013

The 2012 population of the KUC area was 243,842 while population density stood at 3,488 inhabitants per square kilometer with ranges from 7, 858 to 1,057 person per square kilometer. There were 21, 634 housing units and average housing density was 1, 327 per square kilometer with ranges from 2,212 to 320 (Department of Census and Statistics Sri Lanka, 2013). The KUC has emerged as an attractive residential area for commuters from many parts of Sri Lanka, and as a result, many of its agricultural areas, especially former rubber plantations were gradually converted to non-agricultural areas, resulting in 2012 in about 60% of the land area being used for residential LU/LCs and 30% still being used for agriculture (Table 1). In 2011, the KUC had over 600 hectares of paddy land and 32% of the paddy area was abandoned, as a result of rice cultivation in this part of the country being less economically profitable in comparison to production in the north of Sri Lanka where labour costs are lower (Dubbeling, 2014). Salt water intrusions are also an increasing problem resulting in lower rice crop yields and incomes to paddy farmers (Vulnerability Mapping in KUC, 2012).

Table 1: Distribution of Land use – Land covers in the Kesbewa Urban Council Area, Sri Lanka in 2012.

Land use	Area (km^2)	Percentage
Residential	30.171	59.91
Government	0.001	<0.01
Other Land	0.085	0.17
Playground	0.095	0.18
Cemeteries	0.107	0.21
Hotels	0.129	0.25
Commercial	0.164	0.32
Buildup	0.218	0.43
Religious	0.421	0.83
Public	0.452	0.89
Industrial	0.725	1.44
Road	1.404	2.78
Coconut	0.398	0.79
Paddy	10.115	20.08
Other Agriculture	2.380	4.72
Water bodies	3.060	6.07
Marshy Land	0.429	0.85
Total	50.353	100

Source: Urban Development Authority, 2012

2.2 Remote sensing data and software used

A total of 10 images from the USGS server (earthexplorer.usgs.gov) for the KUC study area were obtained (Table 2). Six images exhibited cloudiness or haze and were not used, therefore only four images, three from the Landsat 7 ETM+ and one from the OLI- TIRs sensor Land sat 8 satellites (formerly called LDCM - Landsat Data Continuity Mission) were used in this analysis. Landsat images were analysed and surface temperatures for the KUC study area were extracted using ENVI 5.0 and ArcGIS 10.0 software.

Table 2: Remote sensing images used to estimate Land Surface Temperatures in the Kesbewa Urban Council study area.

Acquisition date	Satellite / Sensor	Path	Row	Band	**Spectral Range** (microns)	Spatial resolution
2001-03-14	Landsat ETM+	147	55	6	10.40 to 12.5	60 Meter
2003-01-24	Landsat ETM+	147	55	6	10.40 to 12.5	60 Meter
2005-02-13	Landsat ETM+	147	55	6	10.40 to 12.5	60 Meter
2014-02-09	Landsat 8 OLI-TIRS	147	55	6	10.40 to 12.5	100 Meter
Images not used in this analysis due to cloudiness and haze						
2013-01-26	Landsat 8 OLI-TIRS	147	55	10	10.60 - 11.19	100 Meter
2013-07-29	Landsat 8 OLI-TIRS	147	55	10	10.60 - 11.19	100 Meter
2013-12-20	Landsat 8 OLI-TIRS	147	55	10	10.60 - 11.19	100 Meter
2014-01-05	Landsat 8 OLI-TIRS	147	55	10	10.60 - 11.19	100 Meter
2014-02-22	Landsat 8 OLI-TIRS	147	55	10	10.60 - 11.19	100 Meter
2014-06-14	Landsat 8 OLI-TIRS	147	55	10	10.60 - 11.19	100 Meter

A requirement for extracting surface temperature from satellite data are similar weather conditions across disparate data acquisition dates. Therefore, precipitation data from the two nearest meteorological stations in the KUC area were analysed and both showed no precipitation occurring the acquisition dates (Table 3).

Table 3: Rainfall condition for two metrological stations during image acquisition dates in the Kesbewa Urban Council.

Acquisition date	Precipitation (mm) in Ratmalana	Precipitation (mm) Boralesgamuwa
2001-03-14	0	0
2003-01-24	0	0
2005-02-13	0	0
2014-02-09	0	0

Source: Department of Meteorology, 2014

2.3 Land Surface Temperature Methodology

Landsat images were georeferenced to the KUC study area and the digital numbers were used to obtain spectral radiance using equations 1a and 1b below. It is well accepted that any object will emit thermal electromagnetic energy as its temperature is above absolute zero (K). Based on this principle, the signals received by the thermal sensors (ETM+/OLI-TIRS) can be converted to spectral radiance using equation 01 (a) (Landsat 7 Science Data User Handbook, 2007) for ETM + and equation 01 (b) (http://landsat.usgs.gov , 2013) for OLI-TIRS.

$$CV_{R1} = ((LMAX_{\lambda} - LMIN_{\lambda})/(QCALMAX - QCALMIN))*(QCAL - QCALMIN) + LMIN_{\lambda}$$

Equation 1 (a)

Where CVR1 is the cell value as radiance; QCAL = digital number; LMINλ = spectral radiance scales to QCALMIN; LMAXλ = spectral radiance scales to QCALMAX; QCALMIN = the minimum quantised calibrated pixel value (typically = 1); QCALMAX = the maximum quantised calibrated pixel value (typically = 255).

$L\lambda = ML*Qcal + AL$ *Equation 1 (b)*

Where Lλ is Top of Atmospheric Radiance in watts/ (m2*srad*µm); ML is the Band specific multiplicative rescaling factor (radiance_mult_band_10/11); Qcal is the band 10/ 11 image; AL the Band specific additive rescaling factor (radiance_add_band_10/11).
Spectral radiances were then used to calculate LSTs for 2001, 2003, 2005 and 2014 using equations 2 and 3. Radiance values from the ETM+/OLI-TIRS thermal band were then transformed to Kelvin using equation 02 (http://landsat.usgs.gov, 2013).

$$T = \frac{K_2}{\ln\left(\frac{K_1 * \varepsilon}{CV_{R1}} + 1\right)}$$

Equation 2

where T is degrees Kelvin;K1 and K2 are calibration constants obtained from the USGS website (Landsat ETM+) and from the header file of Landsat 8 OLI-TIRS images (table 04); CVR1 is cell value as radiance, *ε* is emissivity (typically 0.95).

Table 4: Calibration constants used for *TB* retrieval in Equation 02

	Landsat ETM (Band 6)	Landsat 8 OLI-TIRS (Band 10)
K1	666.09	774.89
K2	1282.71	1321.08

Source: USGS, 2013

Brightness temperature (T_B in Kelvin) were converted to Celsius (C^0) using equation 3 (USGS, 2013). Finally, images were overlaid with available LU/LCs maps and used to characterise LSTs for different LULCs and the KUC study area (Figure 7).

$$T_B = TB\text{-}273 \qquad \textit{Equation 3}$$

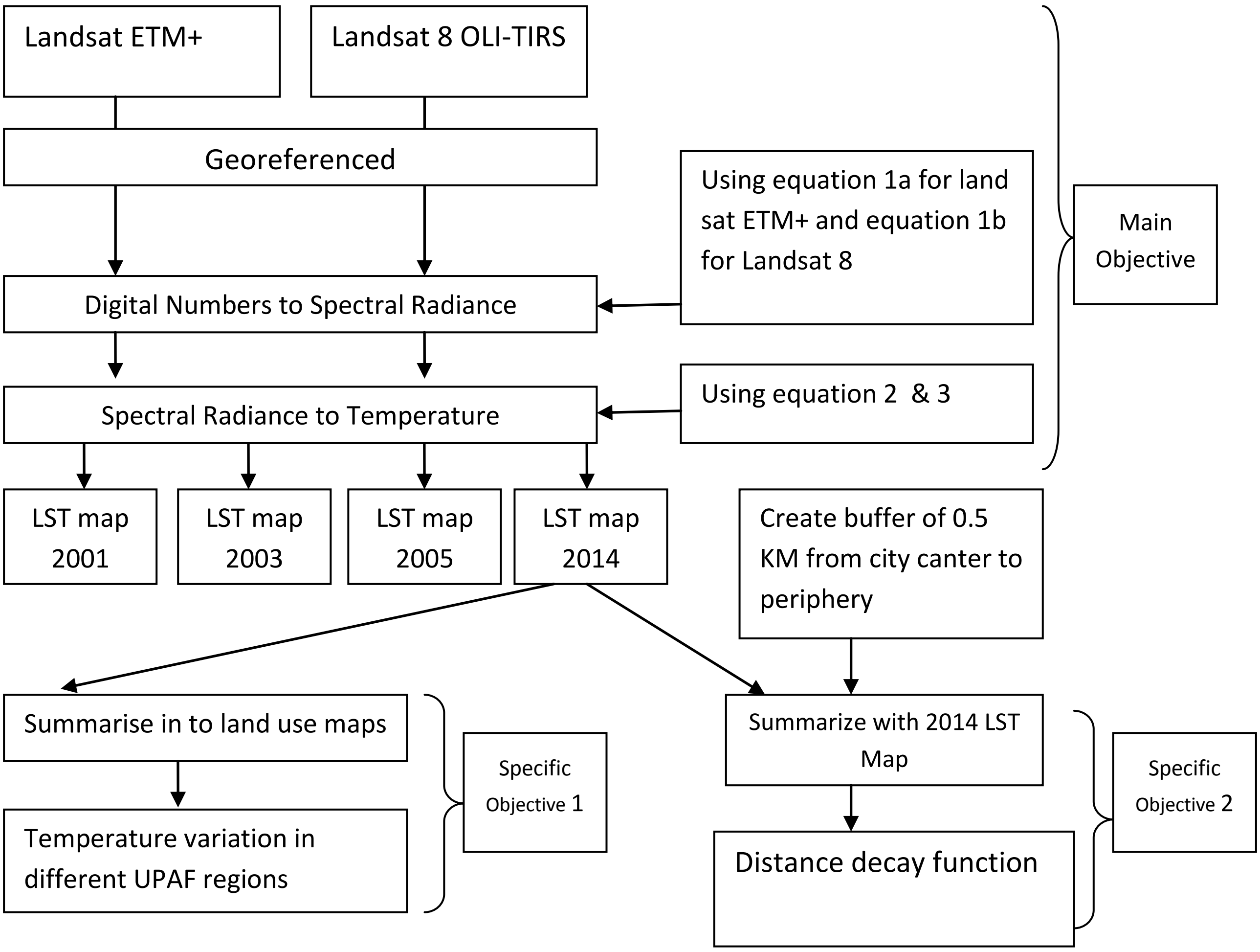


Figure 7: Method for estimating Land Surface Temperature (LST) in the Kesbewa Urban Council study area for 2001, 2003, 2005 and 2014 using the LANDSAT ETM sensor. Note: ETM, Enhanced Thematic Mapper; UPAF, Urban and Peri-urban Agriculture and Forestry.

2.3.1 Method for examining the relationship between land surface temperature and UPAF

Land surface temperature maps were then prepared for 2001, 2003, 2005 and 2014. To examine the spatial variation of LST according to different LU/LC and area with and without UPAF areas, the 2014 LST map was summarised with recent LU/LC maps, using the Zonal Statistics tool of the ArcGIS 10.0 software. Afterwards summarised LST and land use map data were analysed using MS Excel.

2.4 Surface temperature patterns in the KUC

The LST variation in the KUC was analysed using an urban-rural gradient from the KUC city centre (i.e. Piliyandala) to its urban periphery that was established using visual interpretation of Google Earth imagery. The Piliyandala city centre is located at Lat: 6.801782, Log: 79.922664. From this city centre, concentric 0.5 km width zones were created towards the periphery using ARCGIS. Subsequently, population density, housing density, total land area covered by buildings (flow area density), 2014 LST, and LU/LCs data were classified for each 0.5 km zones and converted to different data objects to better visualise changes along the gradient. One transect from the city centre to the periphery along a north to south-southeast direction was established to characterise LST for the gradient during the period studied.

3. Results and Discussion

3.1 Spatial pattern of surface temperature in the KUC area

Table 5 shows the descriptive statistics for LSTs over the KUC area for the years 2001 to2014. Figure 8 shows a graphical representation of the LST variation for this period. The Mean temperature value in 2001 was31.20 C^0 while that of year 2003 was 31.26 C^0; a LST increase of about 0.06 C^0. Mean LST in 2005 was 33.83 C^0 , showing a temperature elevation of about 2.57 C^0 with respect to 2003. Mean LST in 2014 is 34.80 C^0 and shows a 0.97 C^0 temperature increase compared to 2005, and a 3.60 C^0 temperature increase compared to 2001.

Table 5: Descriptive statistics including Minimum, Maximum, Mean and Standard Deviations (SD) of Land Surface Temperature (LST) over the Kesbewa Urban Council study area for representative periods during 2001-2014.

Acquisition date	Minimum LST (C^0)	Maximum LST (C^0)	Mean LST (C^0)	SD LST (C^0)
2001-03-14	26.59	38.96	31.20	1.30
2003-01-24	26.59	39.90	31.26	1.26
2005-02-13	30.17	38.96	33.83	1.24
2014-02-09	31.28	39.22	34.80	1.23

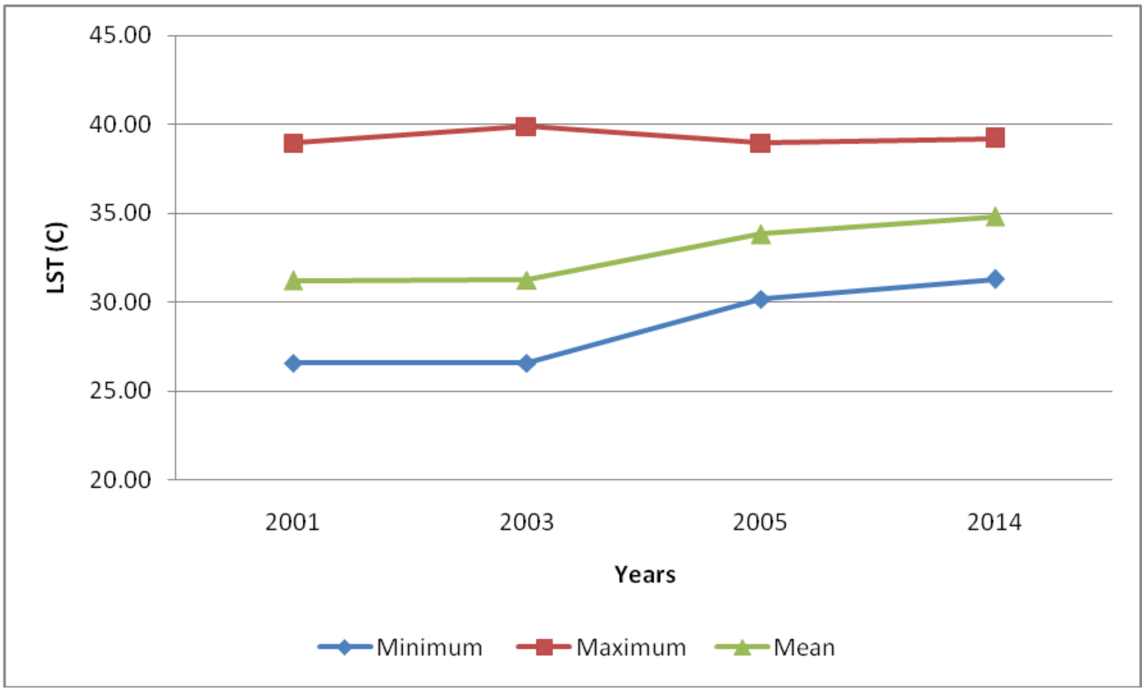
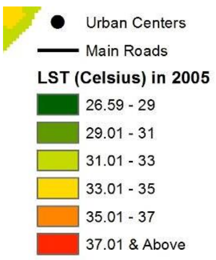


Figure 8*:* Minimum, Maximum, and Mean Land Surface Temperature over the Kesbewa Urban Council study area for representative periods during 2001-2014.

Figures 9 and 10 show the distribution of the extracted surface temperature from 2001, 2003, 2005 and 2014 respectively for the Kesbewa Urban Council Study area. Land surface temperature values in the analysis period varied from 26.59 C^{0} (lowest in 2001) to 39.90 C^{0} (highest in 2003; Figure 9a and 9b). In 2003, the lowest LST remained the same as in 2001, but the highest value increased to 39.90 C^{0}. In 2005, the lowest temperature was 30.17 C^{0} and the highest value remained the same as in 2001 (Figure 10a). Results for 2014 (Figure 10b) show little difference compared to the year 2005 and no noticeable change in highest value. The highest temperature value was consistently observed in the Piliyandala city centre and the lowest value was observed over a large water body (Bolgoda lake) in the southwest of the study area during the analysis period. There was also noticeable spatial variation in the KUC's LSTs representing different geographical characteristics of the city. In highly urbanised areas the extracted surface temperature was relatively high, while highly vegetated areas exhibited low surface temperatures. The central part of the city (Piliyandala junction) reported the highest surface temperature values whilst the lowest surface temperature values were reported in the fringe area which comprises water bodies.



Colour explanations for figures 9 and 10.

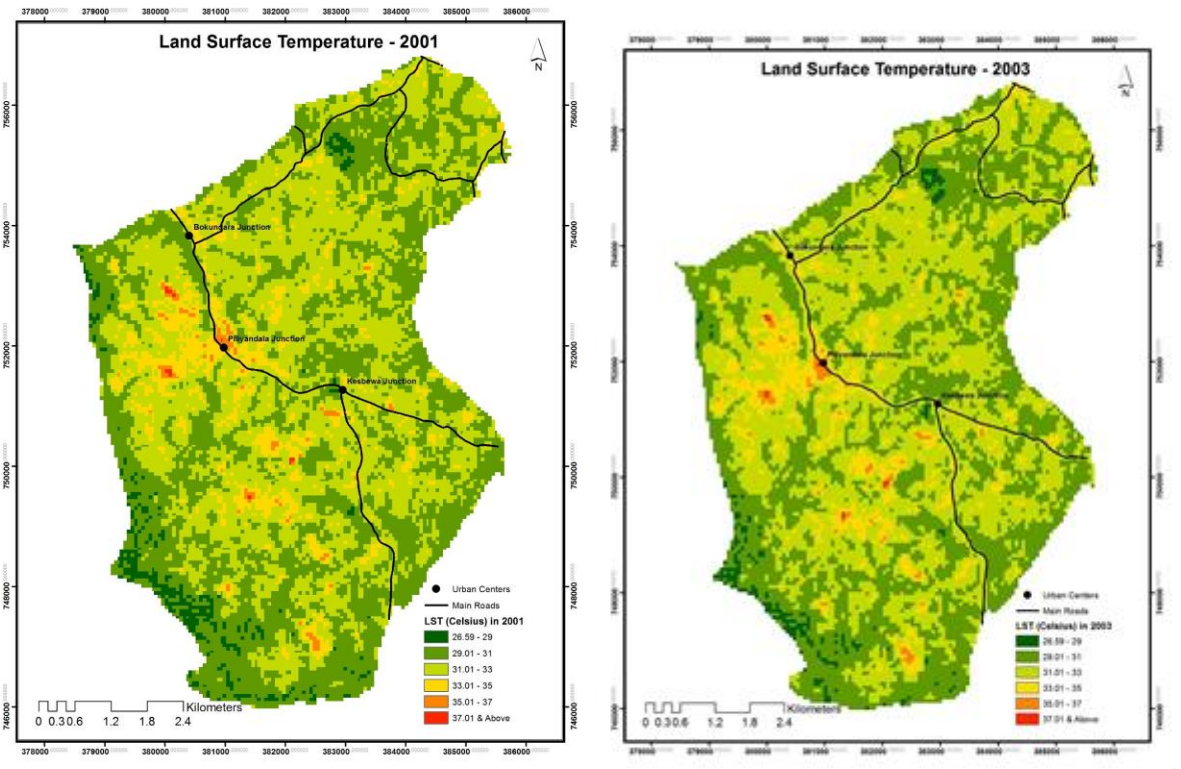


Figure 9 - Land Surface Temperature for 2001 (left) and 2003 (right) in the Kesbewa Urban Council.

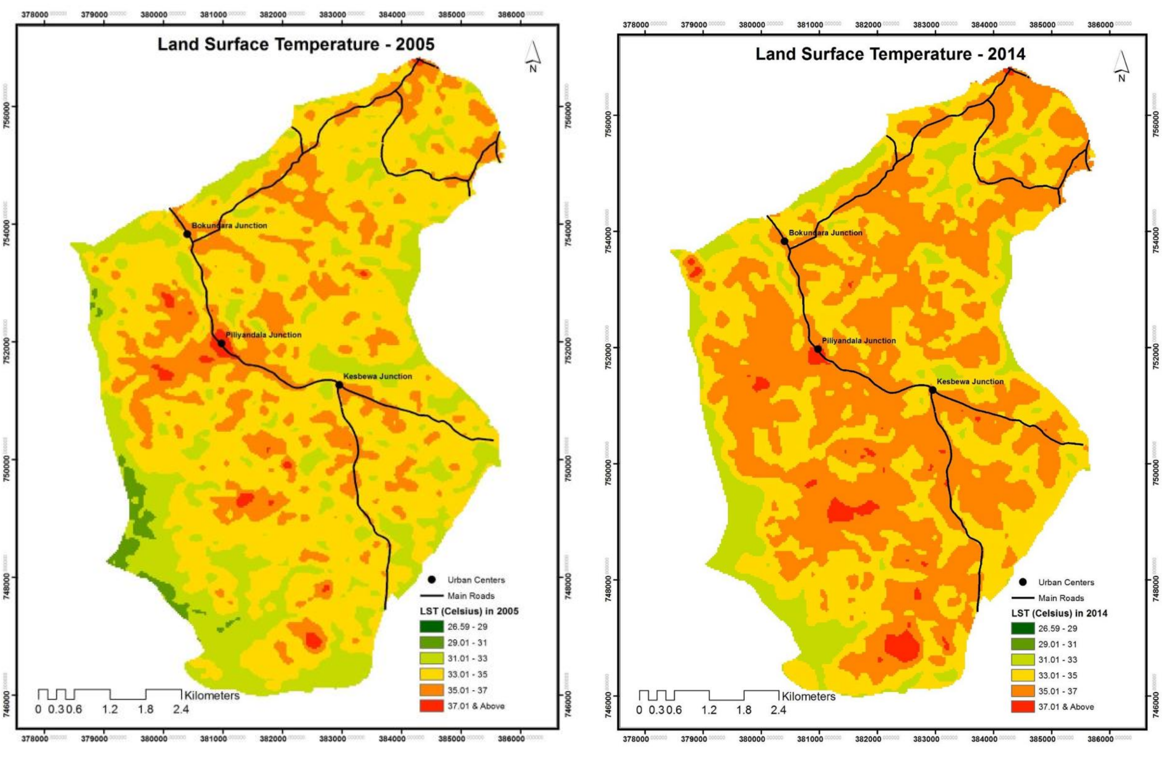


Figure 10 - Land Surface Temperature for 2005 (left) and 2014 (right) in the Kesbewa Urban Council.

Discernable LST values were observed for the different LU/LCs used in the analysis (Table 6). The LSTs in highly urban LU/LCs are 36.11 C^0 while water bodies have LSTs of 34.02 C^0. The second highest LST values were recorded in Commercial areas, followed by Industrial, and road LU/LCs. Residential LU/LCs were characterised by mean LSTs of 35.42 C^0 LST. Figure 11 shows the LST for 2001 (Figure 11a) and 2014 (Figure 11b), a 2014 Google earth image (Figure 11c) and field view (Figure 11d) for the City Center. High pixel values represent red colour and lower values are represented by yellow and green colours. The city centre areas are characterised by high population and housing densities, high vehicular traffic and an absence of vegetated areas.

Table 6: Land Surface Temperature (LST; C^0) differences for Land use Land cover classes in the Kesbewa Urban Council area, Sri Lanka.

Land use	Area (km^2)	% of the area	Minimum LST (C^0)	Maximum LST (C^0)	Mean LST (C^0)	SD LST (C^0)
Built-up	0.21	0.41	35.81	36.11	35.96	0.11
Commercial	0.12	0.25	35.73	35.78	35.75	0.02
Industrial	0.72	1.43	35.33	36.04	35.71	0.22
Road	1.27	2.54	35.23	35.76	35.52	0.19
Residential	30.13	60.13	34.88	35.89	35.42	0.28
Other Land	1.28	2.56	35.03	35.55	35.31	0.17
Other Agriculture	2.38	4.75	34.24	35.44	34.84	0.34
Coconut	0.40	0.80	33.64	35.61	34.63	0.47
Paddy	10.11	20.18	33.47	35.12	34.11	0.41
Marshy Land	0.43	0.86	33.52	34.71	34.09	0.33
Water bodies	3.06	6.10	33.17	34.02	33.51	0.26

SD, Standard deviation

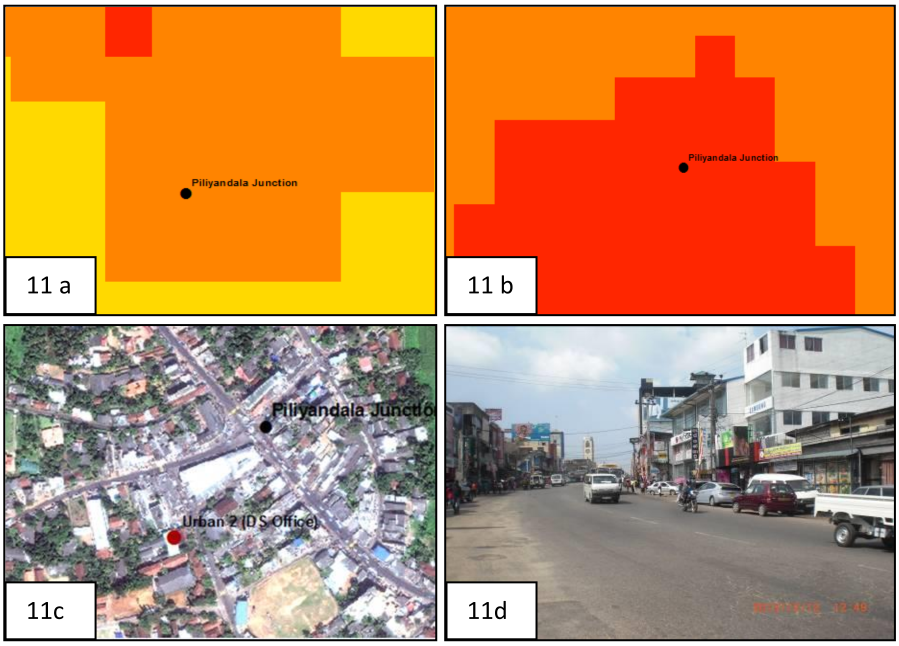


Figure 11a-d: Different views of Land Surface Temperatures (11a and 11b) and the highly urbanised Piliyandala City Centre in Google Earth (11c) and field view (11d).

Conversely water bodies, Marshy Land and paddy land LU/LCs exhibited the lowest LSTs (Figure 12a-d)). When compared to other agriculture lands (Coconut and vegetable growing areas) these demonstrate relatively higher LST values. The KUC study area is covered for about 27 % by paddy, marshy land and water bodies. In terms of the temperature, another important feature is that the minimum temperature value in the built-up area is higher than the average LST of both categories water bodies, marshy land and paddy (Table 6).

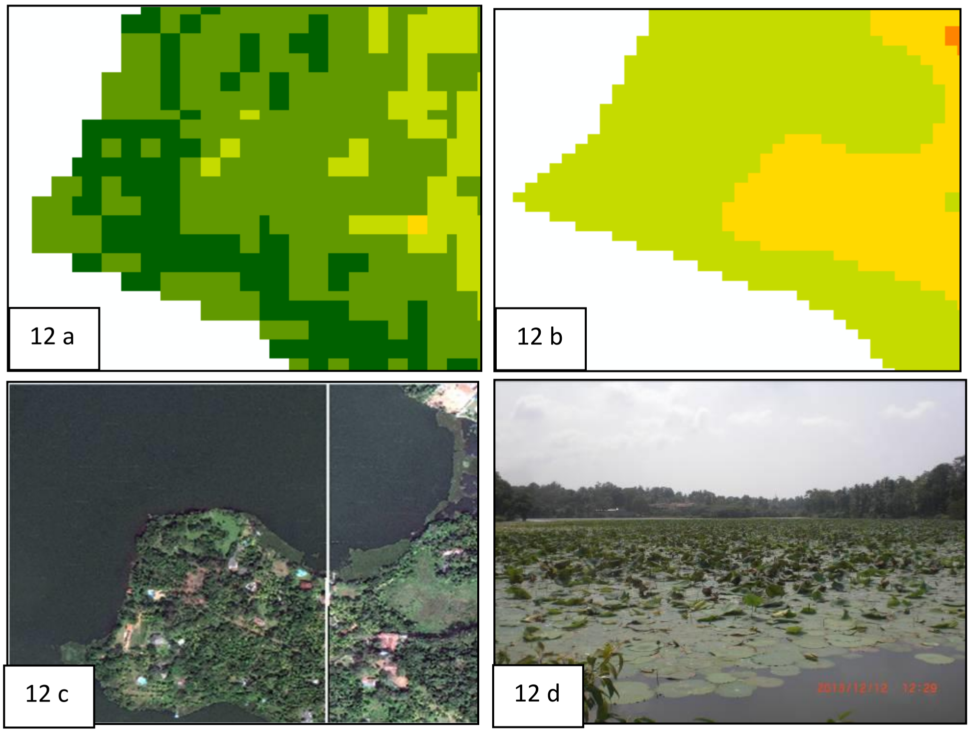


Figure 12: Water area and Land Surface Temperatures in KUC

Most of the areas are under residential LU/LCs, in total covering more than 60 % of the KUC, give average temperatures of 35.42 C^0 ranging from 34.88 C^0 to 35.89 C^0. To better understand the influence of vegetation on residential areas on LSTs we separated the residential LU/LC pixels into those with measurable UPAF vegetation (larger than 253 m^2) and those without vegetation (i.e. non-UPAF) or residential structures in highly urbanised areas near roads where no cultivation or green space was discernable. The average LST was 36.00 C^0 (Figure 13) in homes without UPAF vegetation and LST were higher when compared to homes with UPAF vegetation. Google Earth imagery (Figure 13c) shows LU/LCs typical of non-UPAF vegetation residential areas in the KUC study area.

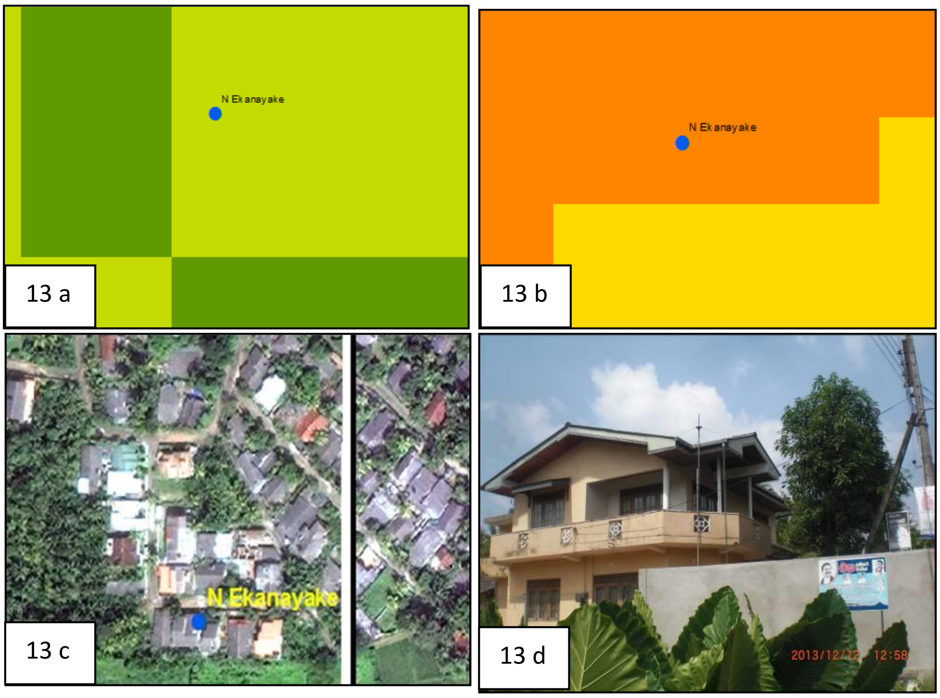


Figure 13: Residential houses without UPAF vegetation and Land Surface Temperatures in the Kesbewa Urban Council.

Figure 14 demonstrates the LU/LCs typical of vegetated UPAF residential areas. The yellow and green coloured pixels in Figure 14a and 14b are noticeable and no higher temperature red colour pixels are visible. Average LSTs for these vegetated residential areas is 34.0 C^0. Agricultural areas that predominate the periphery of the study area (i.e. “Ovitas” as referred to in the KUC study area), excluding rice paddies, show minimum, maximum and average temperature of 34.24, 35.44 and 34.84 C^0 respectively (Figure 17).

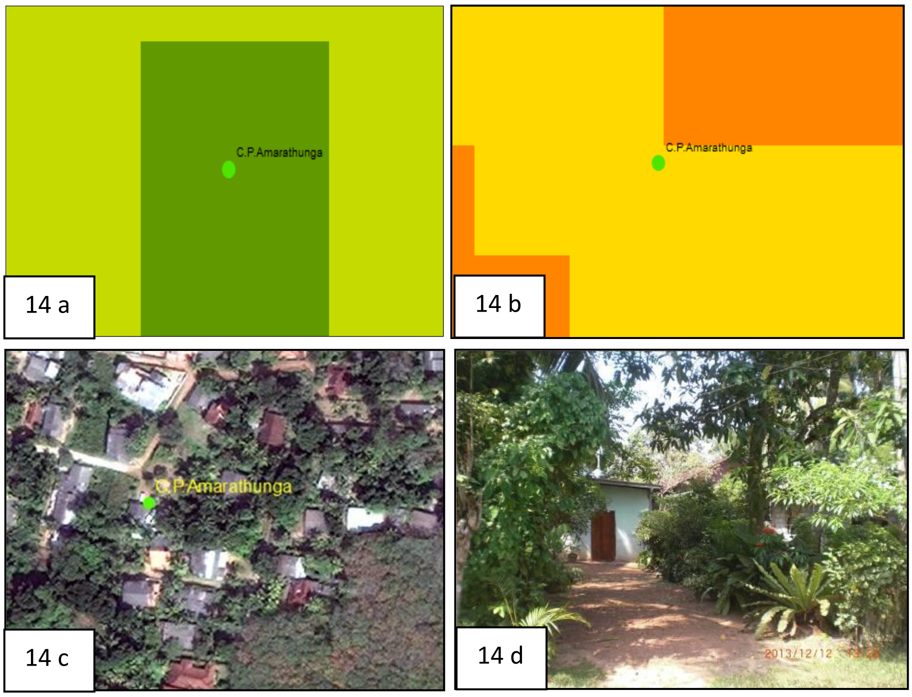


Figure 14: Residential houses with UPAF vegetation cover and LST

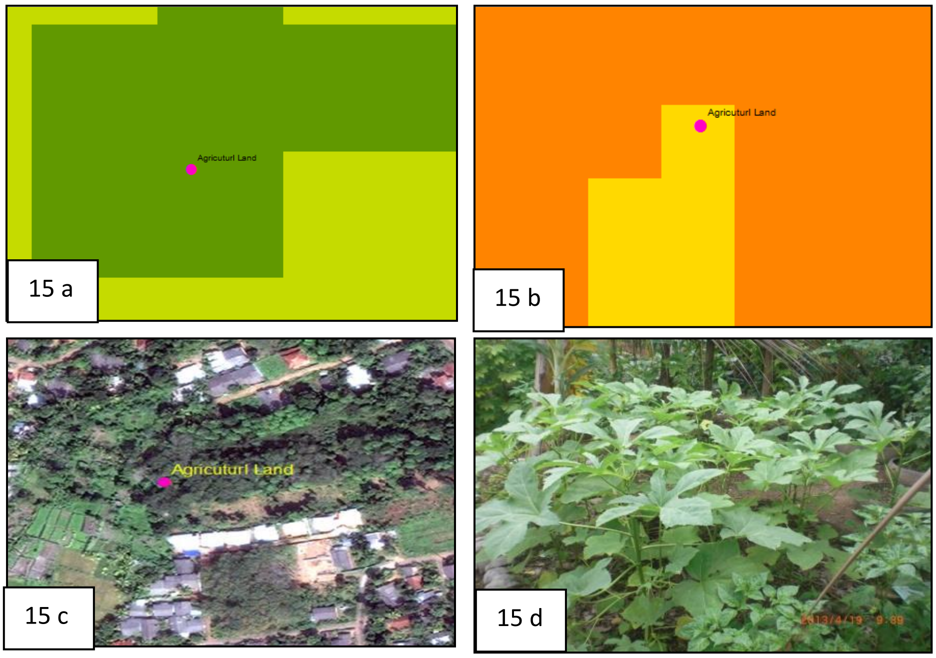


Figure 15: Other agricultural UPAF areas and LST

Overall, we observed an inverse relationship between the amount of vegetation and increased LSTs. This was particularly noticeable in highly urbanised commercial and industrial areas with less vegetation cover. Areas of residential houses without vegetation did have slightly lower LSTs in the LU/LCs compare with highly urbanised areas; paddy, marshy land and water areas had low values of LST. Figure 13 to 15 demonstrate the increased LST as rural vegetated areas become urbanised during the 2001 to 2014 analysis period.

3.2 Gradient variation of LST

Along the urban-rural gradient , 0.5 km concentric circles were generated from the city centre to represent LST values during the analysis period . As shown in Figure 16, LSTs are relatively very high along roadsides and urban built-up areas whereas they decrease towards the city periphery with greater areas of UPAFs .

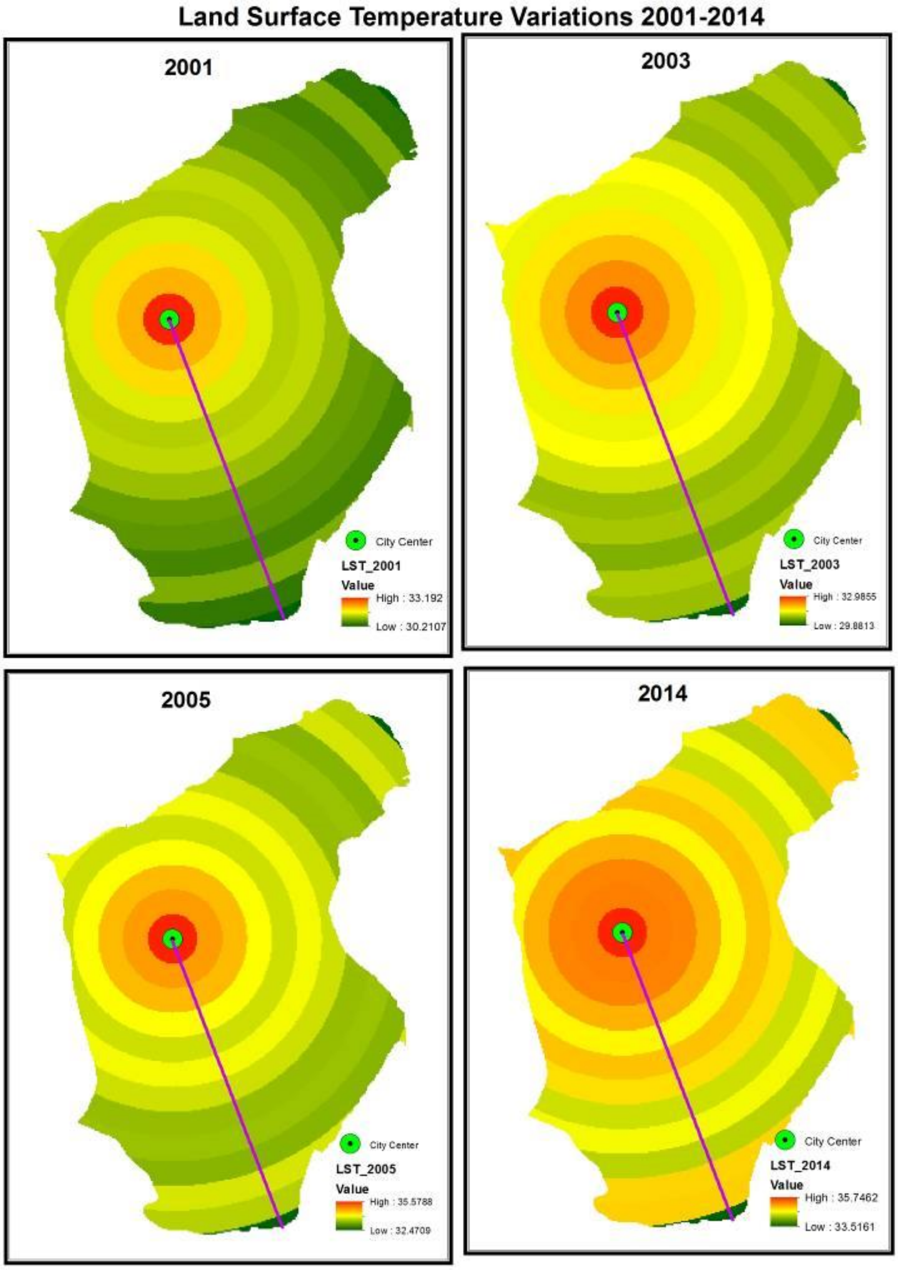


Figure 16: Pattern of Land surface temperature in concentric rings from the Kesbewa Urban Council city centre to its periphery

According to Figure 16 and Table 7, LST in the gradient vary from 29.87 C^0 (lowest in 2003) to 35.75 C^0 (highest in 2014). Most of the red and orange area are built -up and urban residential areas in 2001-2005. In 2014, most of the red and dark orange areas refer to highly urban and urban residential areas. Average LST vary from 31.21 C^0 in 2001 to 33.52 C^0 in 2014. The main cause of these high LST are next to increased building and traffic, temperature and energy emissions from the use of fans and air conditioner during day and night time. Most of the agricultural lands, water bodies and paddy lands are situated in the green areas and yellow areas.

Table 7: Land Surface Temperatures (LST) differences in the Kesbewa Urban Council study area along the urban to rural gradient from the city centre to periphery (C^0)

Acquisition date	Minimum LST (C^0)	Maximum LST (C^0)	Mean LST (C^0)	SD LST (C^0)
2001-03-14	33.192	30.211	31.207	0.520
2003-01-24	32.985	29.881	31.264	0.480
2005-02-13	35.579	32.471	33.832	0.452
2014-02-09	35.746	33.516	34.808	0.321

SD=Standard Deviation

The south-southeast transect extending from city centre to the periphery along the urban-rural gradient is shown in Figure 16. The transect's LSTs (Figure 16) clearly demonstrates the decreasing pattern of LSTs from the city centre to the periphery. The decreasing temperature gradient from city centre southeast to the periphery represents an urban heat island profile for the KUC. Overall, Figure 19 shows a similar pattern in LST in 2001 and 2003,but 2005 and2006 and 2014 show an increasing trend of LSTs in the study area.

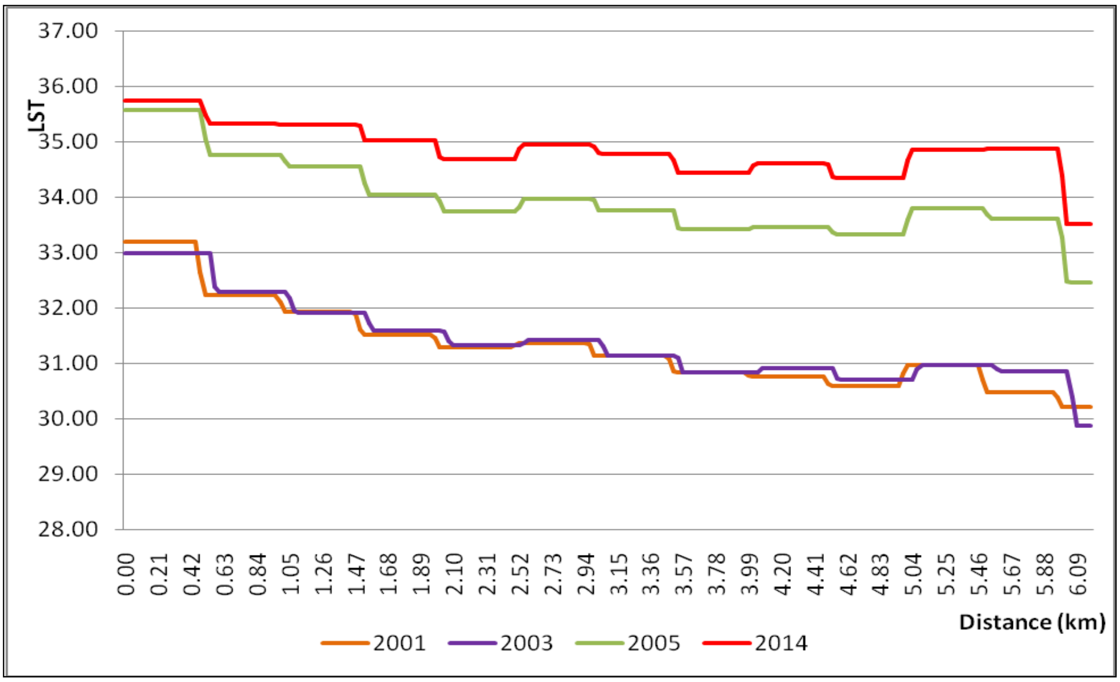


Figure 16: Profile of surface temperature from city center to periphery; distance 0 is city center (high temperature) and the 6 km value is the periphery of the KUC area.

To better understand how LU/LCs along this gradient affect LSTs, we characterised each zone in terms of their LU/LCs (Figure 17). In the 0.5 km circle from Piliyandala city centre more built-up areas can be identified. Built-up area is gradually decreasing up to the 2.5 km circle. Increased temperatures are visible in the near city centre areas (0-2.5 km). Residential areas for all zones are more than 50% of surface area. Paddy areas can be found everywhere except in the 3.5-4.0 km circles. More water area can be identified on 1.5- 6.0 km distance. Based on land use types decreasing trend of LST can be understood from land sue the in city centre to the periphery.

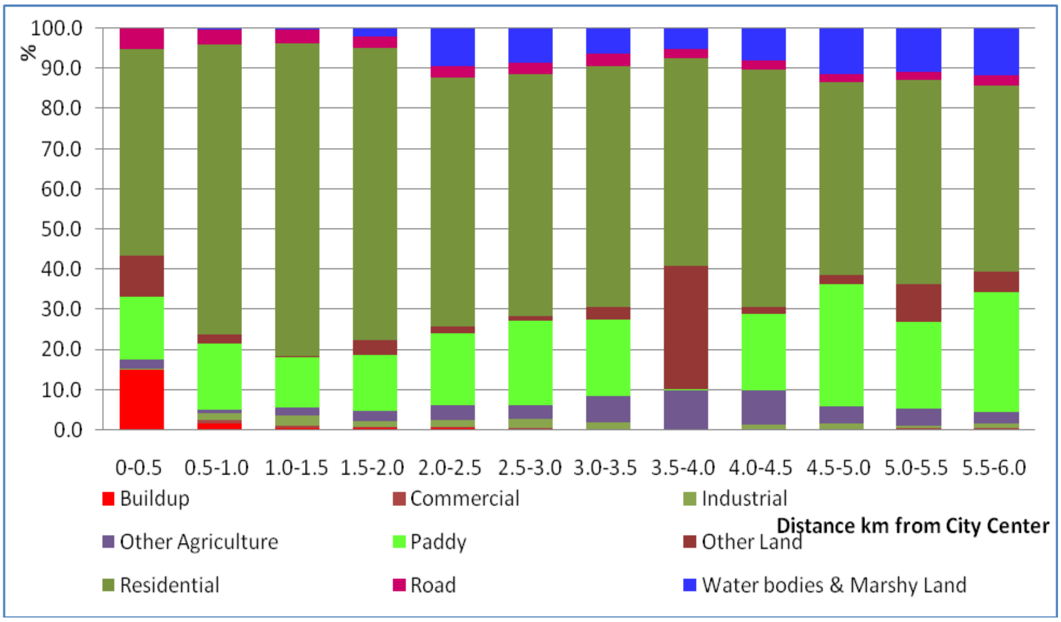


Figure 17. The proportion of land use land covers classes in the Kesbewa Urban Council 's zones

Population density, housing density, built-up area/flow area percentage were also summarised in the urban to rural gradient (Figure 18 and 19). Findings clearly show the decreasing trends in LST, population density, housing density and flow area from city centre to periphery. Within the first four circles (0-2.00 km from the city centre) temperature, population density, housing density and flow area values are higher and this is likely the reason for higher LST around the city area. Less green area and less agriculture area can be found in this area where more land is allocated for residential and commercial purposes.

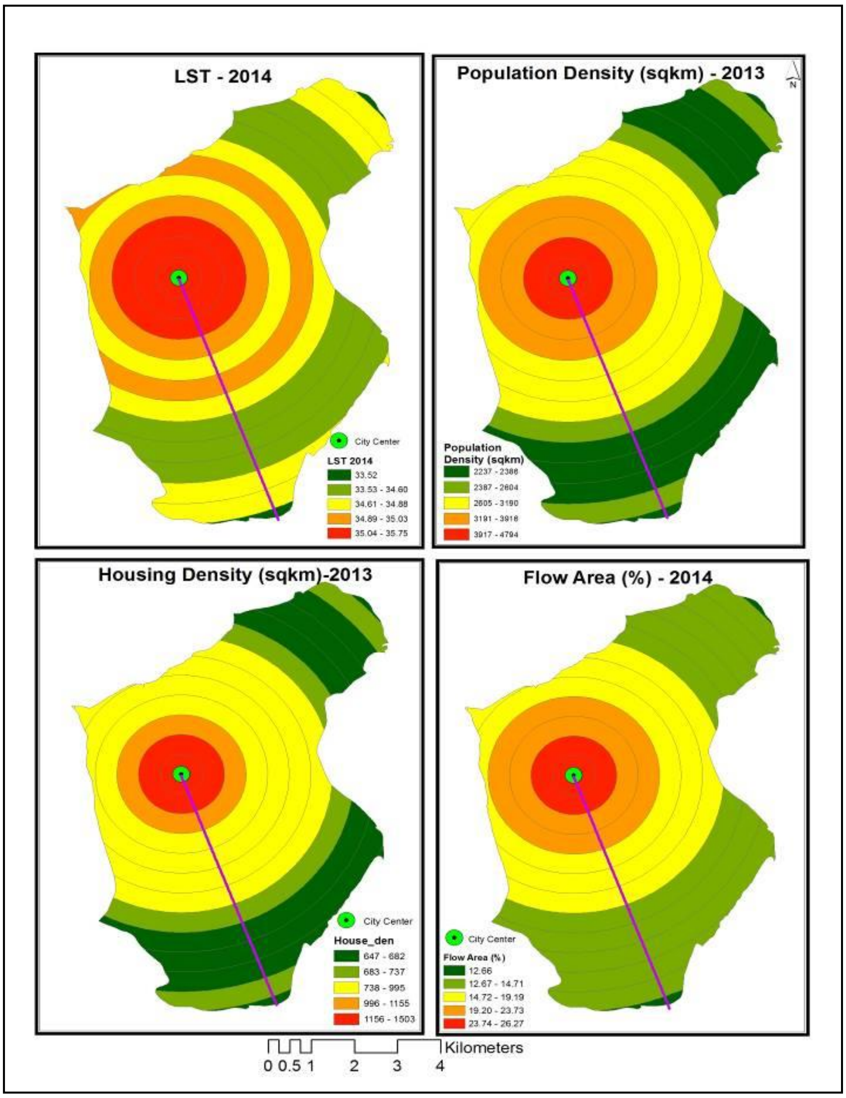


Figure 18. Population density, Housing density, flow area characteristics in the Kesbewa Urban Council's urban to rural gradient

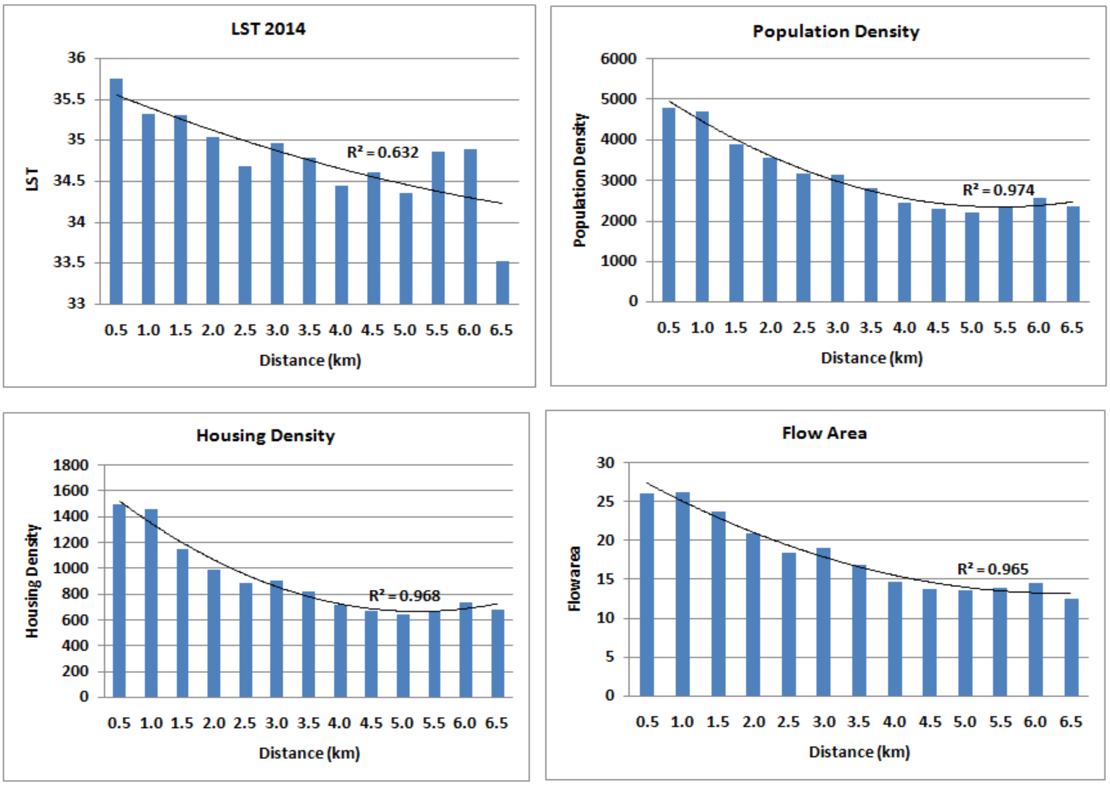


Figure 19: Variation in 2014 land surface temperatures, population density, housing density and flow area along the Kesbewa Urban Council's city centre to periphery

4. Conclusions

This study used remote sensing and spatial analysis to characterise LSTs in the KUC study area from 2001 to 2014. The study was based on available LANDSAT satellite data and used a limited number of images. The analyses were done using ARCGIS and EXCEL. Thus, further ground verification of our LST estimates are needed.

Findings show that LSTs of the KUC increased during 2001-2014 due to human activities and land use and land cover changes. The LST of the KUC shows a strong differentiation in LST between urban and more vegetated areas. Overall, this study found:

1. Very high temperatures in the highly urbanised areas
2. High temperature in residential non UPAF areas
3. Moderate temperature in residential areas with UPAF
4. Moderate temperatures in UPAF areas
5. Low temperature in water, marsh land and paddy areas.

Green vegetation and UPAF have shown to have moderating effects on LST temperatures. Higher LST directly affect human comfort levels and energy use.

The study showed that green spaces help urban areas adapt to the impact of climatic change regardless of whether they are parks, private or urban agriculture gardens, water bodies or street trees, but the size, vegetation type and proportion of coverage all influence the level of impact.

As climate change and temperatures increases, green spaces are likely to become increasingly important, especially to relieve the effects of raised temperatures. Productive green spaces bring added values of income generation and food security and provide opportunities for organic waste management and recycling.

Increasing the area of UPAF in and around the city centre will be help to control the increasing and expected higher LSTs in KUC area. However, land use and land cover trends in the KUC area show that vegetated areas are increasingly being converted to denser non-UPAF built up areas.

Especially the preservation and increase of open space within the city centre, next to protecting the peri-urban green zone, should be promoted in helping adaptation. This clearly has implications for policies to encourage infill development, higher housing densities and reduce the loss of garden and green areas. Further protection and promotion of urban agriculture and home gardening in the city can be achieved by including UPAF in the Kesbewa Urban Development Plan, expanding the home gardening programme and by education, social pressure and incentives (for example supporting rainfall harvesting and composting use).

A different climate, though, will have implications for the costs of, and approaches to, maintaining productive green spaces such as increased watering during droughts, soil and drainage management to avoid flooding during increased intense rainfall and greater pressure on built-up spaces as they have to be used more intensively.

Clear guidance is needed for local and provincial authorities and other practitioners on how best to manage public urban productive green spaces in order to respond to climate change.

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