Chapter 23

Evaluation of Urban Land Surface Temperatures and Land Use/Land Cover Dynamics for Palakkad Municipality, Kerala, for Sustainable Management

P. Dhanya , **K. Jayarajan** , **and Suresh Selvaraj**

Abstract The rapid urbanisation and land use/land cover (LULC) changes have resulted in the unsustainable growth and rise in heat islands (UHI) in Indian cities. Palakkad is one such city in Kerala, which is known for its relatively higher temperatures than other parts of the state. Therefore, this study was designed to quantify the Land Surface Temperature (LST) dynamics of Palakkad city in response to the LULC change during 2001–2021 using temporal Landsat datasets. Landsat Imagery 7 and 8 of 2001 and 2021 for summer and winter months were processed. The analytical outcomes reveal that mean LST for winter season was 27.07 °C during 2001 and that has increased to 28.35 °C during 2020. Whereas in summer, the mean LST that was 28.59 °C in 2001 has escalated to 29.32 °C during 2021. The results also display a significant decline in vegetation cover from 13.4 to 2.48 km^2 and doubling of built-up areas, i.e. from 7.53 to 16.05 km^2 during 2001–2021. Similarly, the areas under water bodies have shrunken from 2.18 to 1.14 km^2 during 2001–2021. Further, the difference in the rise in the mean land surface temperature during the years 2020 and 2001 is more (1.99 °C) during summer season than winter season (1. 28 °C). Diurnal temperature range in LST between 2001 and 2020 LST has increased slightly during winters and decreased (−0.37 °C) during summers. Significant rise in day and night temperature is likely in future under RCP 4.5 scenario. Due to this, a significant increase in urban heat island (UHI) is seen for central, north-western, and north-eastern parts of the municipality. This type of micro-level research throws useful insights into the process of smart city development, policymaking and planning and heat island mitigation within the Palakkad city limits. The drastic rise in urban settlements and reduction in green cover in the north-western parts requires urgent action plans as envisaged in India's NDCs and SDGs for wellbeing of the inhabitants.

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Introduction

Urban areas with their high density of population confront pressures such as resource crunch, unhealthy environments and climate change impacts. Similarly changing land use and land cover dynamics due to urbanisation is regarded as the critical factor contributing to global warming. It is evident that the natural vegetation has declined in urban areas (Daneshvar et al. 2019). The modified land surface in cities affects the storage and radiative and turbulent transfers of heat and its partition into sensible and latent components. The relative warmth of a city compared with surrounding rural areas, known as the urban heat island (UHI) effect, arises from these changes and may also be affected by changes in water runoff, pollution and aerosols. Urban heat island effects are often very localised and depend on local climate factors such as windiness and cloudiness (which in turn depend on season), and on proximity to the sea (IPCC 2007). The rapid growth in population in India and a resultant rise in GHG emission levels have caused significant changes in the microclimatic and macroclimatic conditions, especially in cities. Any surge in urban temperature has the potential to disturb people either directly or indirectly (Rahman et al. 2019). McKitrick and Michaels (2004) and De Laat and Maurellis (2006) attempted to demonstrate that geographical patterns of warming trends over land are strongly correlated with geographical patterns of industrial and socio-economic development, implying that urbanisation and related land surface changes have caused much of the observed warming. However, the locations of greatest socio-economic development are also those that have been most warmed by atmospheric circulation changes. Widespread urban expansion is happening across the globe, especially in South Asian countries, and 250 million more people are expected to live in cities in South Asia over the next 15 years (Kotharkar et al. 2018; Ellis and Roberts 2016). Rapid expansion of urban areas causes severe environmental degradation in the thickly populated areas. World Bank has reported that South Asia's urban population grew by 130 million between 2001 and 2011 and is poised to rise by almost 250 million by 2030, and majority are living in informal settlements (World Bank 2016). Moreover, severe environmental degradation is also anticipated due to rapid urbanisation in India (Bharath et al. 2018; Daneshvar et al. 2019).

Intergovernment Panel on Climate Change has warned that the rise in mean temperatures and heat waves in the Indian Ocean caused by climate change are reducing monsoonal rains over central regions while increasing rains in south India, creating flash floods (IPCC 2022). Urban heat island is one of the significant causes of urban sprawl (Raj et al. 2020a). Seasonal distribution of aerosol loading seems to have impacted day and night SUHII in the urban areas of major Indian cities (Pandey et al. 2014). Factors such as coverage area, climate and weather variations, vegetation type, soil moisture, street geometry and construction materials cause or

modify the intensity of Urban Heat Island (Thomas and Zachariah 2011). The surge in temperature leads to more recurrent and intense extreme heat events which cause adverse heat-related impacts and rise in physiological discomfort levels for living organisms, human fatalities and economic damages. Apart from this, disparities in evaporative cooling due to impervious surfaces such as roads, sidewalks, driveways and parking lots, buildings and industrial areas may lead to a rise in not only daytime UHI but also nocturnal heat islands.

Advanced spatial information technologies like satellite remote sensing help to understand the spatio-temporal changes that happen in and around the globe. It has become more common to investigate spatio-temporal UHI differentiations and LST changes using the thermal approach of remote sensing. Various remotely sensed indeces, namely the soil-adjusted vegetation index, normalised difference building index and normalised difference drought index, from MODIS, Landsat TM and ETM imagery have been utilised to understand the UHI spatial patterns by many researchers (Bashit et al. 2020; Nguyen et al. 2021; Yang and Santamouris 2018). Moderate Resolution Imaging Spectroradiometer (MODIS) data during the monsoon season (June–August) over megacities of Asia, including Dhaka was utilised to understand the seasonal variation (Itzhak-Ben-Shalom et al. 2017; Kotharkar et al. 2018).

The state of Kerala has faced drastic changes in land use land cover and climate changes in the recent past and is projected to further undergo warming as well as a shift in rainfall patterns and its intensities (SAPCC, Kerala 2014). The rise in temperatures is reported by several researchers. The state is also witnessing severe flooding and landslides in recent years; however, certain research studies suggest that the key problem that Kerala may face is likely to be drought (Mishra et al. 2020). Policy level action plans are envisaged to mitigate and adapt to climate change impacts. Some regions and communities will be more vulnerable to these impacts. Hence, it is the responsibility of the scientific communities to study the local context of vulnerabilities in detail wherever they operate their research. The present study area, Palakkad district, has a unique topography that can influence the local climate. The orography of Western Ghats influences Kerala's climate. Bharathapuzha basin is the largest river basin in Kerala. Apparently, the water flow is relatively less compared to other long rivers in Kerala because a large portion of the basin is located in the drier regions of Palakkad Gap and Tamil Nadu. Loss of forest cover on the Ghats could affect the rainfall patterns and land surface temperatures. A reduction in green cover and rapid urban growth has resulted in flash floods in Palakkad city during the 2019 and 2020 floods. Flash flood was caused due to reduced seepage of excess water from the ground because of reduced green cover to arrest the intensity of runoff and increase in built-up areas, especially in urban and suburban areas. Nikhil Raj and Azeez (2010) has opined that the annual rainfall pattern of all the stations showed a trend of significant decline, as the years proceed. Krishnakumar et al. (2009) have also reported a significant decrease in the south-west monsoon in the state and an increase in the north-east monsoon rainfall.

Ecosystem-based adaptation is essential for the sustainable management of urban areas. Enhancing green cover is considered as the key step in managing and mitigating heat island effects in India's Nationally Determined Contribution

(INDC) (MoEF 2018). Not only national or state action plans, but district administration must also make action plans to tackle climate change while addressing critical issues. Green India Mission is one such program that aims to sequester carbon emissions and negate the impacts of warming and rise in pollution levels. The present study attempts to give a better understanding of the urban heat island effect in the municipality of Palakkad based on satellite remote sensing.

Materials and Methods

Study Area

Palakkad is the largest district in Kerala, located at the foot of the Western Ghats; this is the gateway to Kerala from North due to the existence of the Palakkad Gap in the western ghat. It is bordered on the east by the Coimbatore District of Tamil Nadu, on the north and the north-west by Malappuram district, and on the South by Thrissur District, Kerala. This district is divided into six taluks and seven municipalities. It has a total area of 4482 km^2, out of which 400 km^2 is urban and 4082 km^2 is rural. Out of the total population of Palakkad, 3,119,027 in the district, 676,810 are in urban areas and 2,133,124 are in rural areas. Palakkad Municipality is one of the fast-growing urban centres centrally located in the state. It is located between 09^0 45^I N and 10^0 20^IN latitude and between 76^0 10^I E and 76^0 35^I E longitude (Fig. 23.1). Palakkad Municipality is blessed with many small and medium rivers which are the tributaries (Kalpathy, Malampuzha and Kannadi river) of the Bharathapuzha river. This district is the largest producer of rice hence known as the granary of Kerala. The district is interlaced with hilly tracts and has 136,257 h of reserve forest including Silent Valley, a national park in Kerala.

It has a tropical Monsoon climate. The summers are much rainier than the winters in Palakkad. According to Koppen and Geiger, this climate is classified as Aw. The average annual temperature in Palakkad is 25.9 °C/78.6 °F. March and April are the hottest months on record (Fig. 23.2a) 29.1 and 28.2 °C temperature, respectively. Diurnal Temperature Range (DTR) is maximum during February and minimum during July month. A very high amount of precipitation is received in Palakkad, mainly due to the South-West Monsoon. June and July are the wettest months, and the total annual rainfall is around 83 in (210 cm) with an average 129 of rainy days annually; the major part of the rainfall is from the South-West Monsoon (Fig. 23.2b). December and January are the coolest months on record. Air temperatures range between 20 and 36 °C. June and July have the highest humidity, and February has the lowest recorded humidity over the study period (Fig. 23.2c).
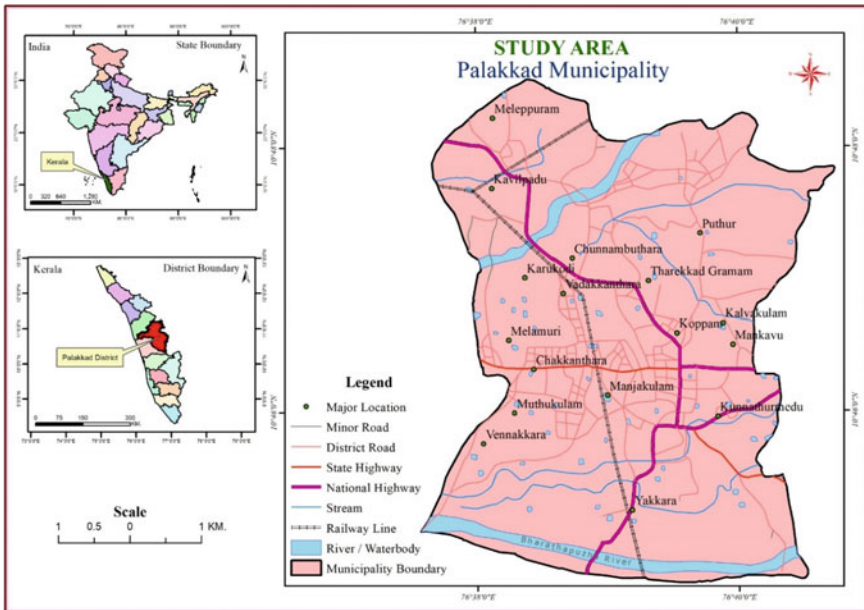
**Fig. 23.1** Map of the study area and wider surroundings

Land Surface Temperature

Data Sources

The details of the data sources used for LST Calculation are given in Table 23.1.

Methods

The data on land surface temperature is downloaded from the following websites (Table 23.1). Satellite images, viz. Landsat 7 and Landsat 8, were downloaded from (https://earthexplorer.Usgs.gov/; accessed on 11th January 2022) for the years 2001 and 2020 according to specific paths and rows for the study area during January (winter) and March (Summer) time. Dewan et al. (2021) has clearly stated the reason behind selecting the winter and summer months separately for UHI studies. As for calculating LST and LULC and UHI classification, the images were pre-processed and analysed in QGIS 3.6 and Arc GIS 10.4. The following Table 23.1 flowchart represents the data sources and process of this study. LST, the skin temperature of the ground, is identified as a significant variable of microclimate and radiation transfer within the atmosphere (Suresh et al 2016; Daramola et al. 2018). Landsat 8 OLI data has Thermal Infrared Sensor (TIRS) with two bands (band 10 and band 11 with 100 m resolution) which is useful in providing more accurate surface temperatures.
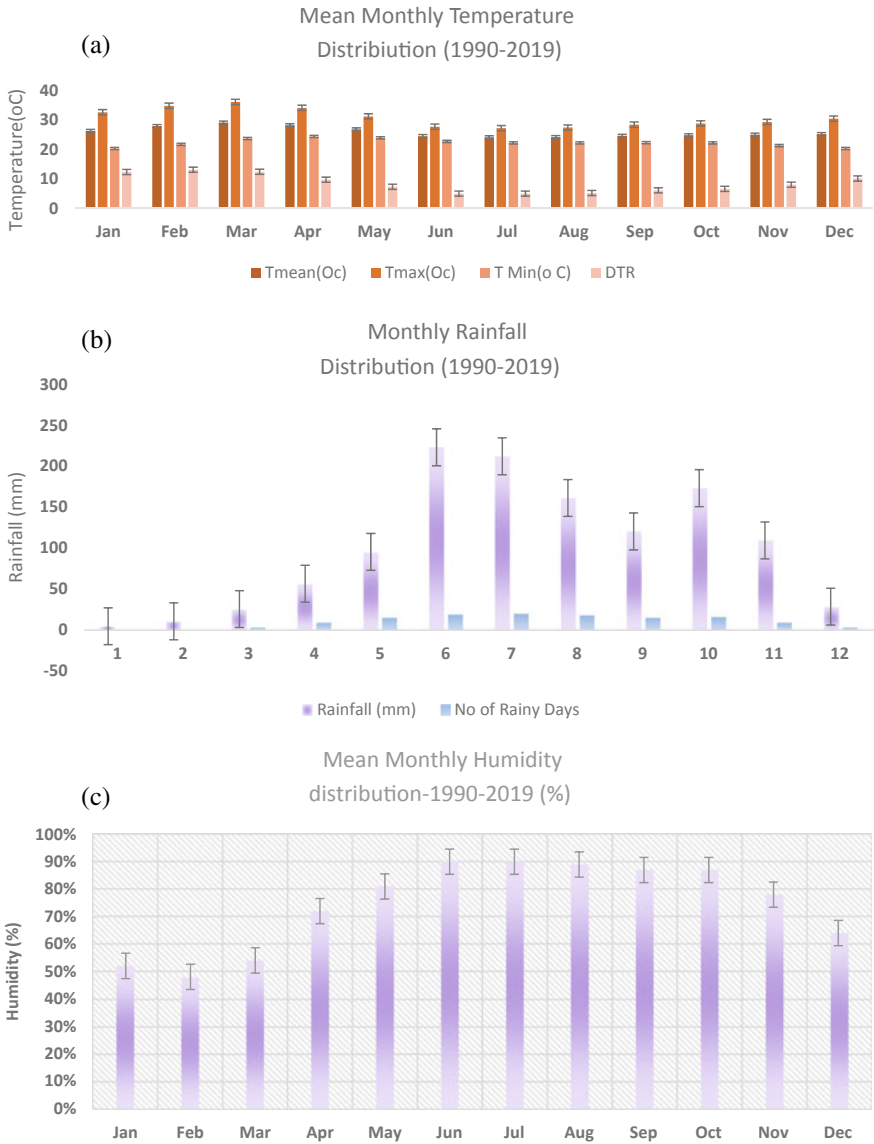
Fig. 23.2 Observed monthly mean climate of the Palakkad city from (1990 to 2019). **a** Mean Temperature distribution. **b** Mean monthly rainfall distribution for Palakkad. **c** Humidity distribution (%)

Table 23.1 Source of data for LST calculations

Sl. No.	Parameter	Data source
1	2001 January LST	https://earthexplorer.usgs.gov/-Landsat 7 ETM+ C1 Level-1,Path 144, Row: 053
2	2001 March LST	https://earthexplorer.usgs.gov/-Landsat 7 ETM+ C1 Level-1,Path 144, Row: 053
3	2020 January LST	https://earthexplorer.usgs.gov/-Landsat 8 OLI/TIRS C1 Level-1,Path 144, Row: 053
4	2020 March LST	https://earthexplorer.usgs.gov/-Landsat 8 OLI/TIRS C1 Level-1,Path 144, Row: 053

In the LST calculation, two algorithms have been employed to retrieve LST from satellite thermal bands, i.e. B6 (60 m resolution) in Landsat 7 ETM+ and TIRS bands from Landsat 8 Operational Land Imagery. To derive LST from Landsat 7, Landsat handbook procedure (https://www.usgs.gov/media/files/landsat-7-data-users-handbook) was applied. There are three steps involved in generating LST from Landsat 7 data. In remote sensing, sensor radiances are generally stored in digital numbers (DN). Therefore, the first step is to convert DN value to the radiance value by applying Eq. 23.1.

$$L\lambda = \left(\frac{(LMAX_\lambda - LMIN_\lambda)}{QCALMAX - QCALMIN} \right)(QCAL - QCALMIN) + LMIN_\lambda \quad (23.1)$$

where $L\lambda$ = Spectral Radiance
QCAL = the quantised calibrated pixel value in DN
$LMAX_\lambda$ = Spectral radiance scaled to QCALMAX in (watts/(m^2*sr*μm))
$LMIN_\lambda$ = Spectral radiance scaled to QCALMIN in (watts/(m^2*sr*μm))
QCALMIN = Minimum quantised calibrated pixel value (corresponding to $LMIN_\lambda$) in DN (typically = 1)
QCALMAX = Maximum quantised calibrated pixel value (corresponding to $LMAX_\lambda$ in DN (typically = 255).

Now, the calculated radiance value has been converted to Brightness Temperature (BT) (in Kelvin) by applying Eq. 23.2.

$$T = K2 \big/ \left(In\left(K1 \big/ L\lambda + 1 \right) \right) \quad (23.2)$$

where
T = The at-sensor temperature in Kelvin
$K2$ = The calibration constant 1282.71 in degrees Kelvin
$K1$ = The calibration constant 666.09 in Watts/(m^2 * sr * μm)
$L\lambda$ = The spectral radiance from Eq. 23.1.
Finally, the BT Kelvin value has been converted to degree Celsius through Eq. 23.3.

$$LST = T - 273.15 \tag{23.3}$$

In contrast to Landsat 7 handbook procedure, in Landsat 8 single Window Algorithm (Suresh et al 2016) has been adopted (Equation-4) to generate LST from Landsat 8 OLI data for the research region (Fig. 23.4). The LST is the relative temperature determined using the following algorithm: BT, the wavelength of emitted radiance and LSE (Choudhury et al. 2021; Suresh et al 2016). Vegetation proportion calculation, emissivity calculation, LST calculation, etc., were executed to calculate LST from Landsat 8 data.

$$LST = BT/1 + (W * (BT/p) * \ln(e)) \tag{23.4}$$

where

BT= At satellite temperature

W=Wavelength of emitted radiance (11.5 µm)

$p = h*C/S$ (1.438*10∧ −2 mk)

$p = 14380$

$e =$ Emissivity ($e = 0.004$ Pv $+ 0.986$)

Pv = (NDVI-NDVImin/NDVImax-NDVImin)^2

where: BT represents TOA brightness temperature (degree Celsius), and λ represents the wavelength of emitted radiance. Land Surface Emissivity (LSE) is the emissivity of any object and can be defined as its ability to measure the emitted infrared energy required to convert BT readings to surface temperature.

Land Use Land Cover (LULC)

Land use simply refers to the human uses of land. The term land use relates to the human activity or economic function associated with a specific piece of land (Lillesand et al. 2008). It means how the land is being used by human beings (Jensen 2013) or can be considered as the human employment of land (Meyer and Turner 1992). Land use change occurs in various forms, including both changes in area and changes in the intensity of use (Houghton 1994). Fundamentally, it can take two forms: conversion from one category of land use to another and modification of conditions within a category (Meyer and Turner 1992). The present study adopted a modified land use classification of NRSC to reflect the local scenario of Palakkad Municipality. Land use maps were prepared for two different periods: 2001 and 2021. Under Supervised classification, Maximum likelihood technique has been applied for image classification.

Urban Heat Island study

It is anticipated that the detrimental effects of UHI would be intensified in the future as both temperature and amount of urban area are expected to increase (Dutta et al. 2021). The Urban Heat Island study was conducted for winter and summer. The formula used for classification is given below.

$$UHI = (T - Tm)/Tsd \qquad (23.5)$$

where

T = Actual surface temperature of each pixel;
Tm= Mean surface temperature;
Tsd = Standard Deviation of surface temperature.

Results and Discussions

Changes in Land Use Land Cover and Land Surface Temperatures

The land surface temperature was downloaded and processed to under-stand the temporal and spatial changes during the summer and winter months. Warming trends are clearly noted for over the analysed period as the mean LST for March month has increased by 5.51 °C than in winter, the rise in warming is 3.38 °C. The observed rise maximum LST for March month is way too higher (4.97 °C) in 2020 than in the year 2001. However, during winter months, the rise in LST in 2020 is 2.35 °C compared to 2001. In the study area, warming is more during March than in winter (Table. 23.2). Warming is more towards the central and southern sides of the Municipality. It is noteworthy that the north-western corner of Municipality that was not much affected by warming in 2001 has been completely altered as a hot spot of warming by 2020. Urban expansion influences the minimum temperature to a greater extent than the maximum temperature in the winter season, and this decrease in temperature variations in the winter period has been earlier reported by several researchers (Gophen 2014; Argüeso et al. 2013) (Tables 23.3 and 23.4).

Table 23.2 LST statistics

Sl. No.	Parameter	Min	Max	Mean	S.D
1	2001 January LST	21.94	31.64	26.20	1.63
2	2001 March LST	24.97	34.46	29.36	1.35
3	2020 January LST	24.48	33.99	29.58	1.24
4	2020 March LST	30.52	39.43	34.87	1.19

Table 23.3 Area under each land use and land cover classes in 2001

Land use land cover	2001 Area in km^2	Area in %
Agricultural land	13.4	47.75
Built-up	7.53	26.84
Mixed trees	4.81	17.14
Open space	0.14	0.5
River/water body	2.18	7.77
Total	28.06	100

Table 23.4 Area under each land use and land cover classes in 2020

Land use land cover	2020 Area in km^2	Area in %
Agricultural land	2.48	8.84
Built-up	16.05	57.2
Mixed trees	6.31	22.49
Open space	2.08	7.41
River/water body	1.14	4.06
Total	28.06	100

The land use land cover analysis has shown that the area under agricultural area or vegetation has reduced by 38% from the year 2001–2020 due to urban expansion. The maximum increase has been noted for the built-up areas. The areas of water bodies also have been reduced by −3.71%. (Fig. 23.3).

Urban Heat Island for Palakkad Municipality

Urban Heat Island Statistics: 2001–2020

Anthropogenic activities have created Urban Heat Islands phenomena in a majority of the cities in India. The Urban Heat Island intensity at Palakkad Urban Municipality (PKDM) can be considered as moderate to high during both winter and summer seasons and is seen to associate well with the surge in settlements. Highest observed urban heat island intensity in PKDM was 8.73 in winter during 2001, which has decreased to 4.9 °C during winter, 2021, indicating an increase in chillness over the period. The maximum observed UHI intensity during summer was 1.21 °C in 2001, and it has increased to 3.02 °C by 2021, indicating increasing extremities. The spatial and temporal distribution of UHI intensity for winter and summer seasons is shown in Table 23.5 and Figs. 23.4, 23.5 and 23.6.

Negative UHI has been noted in the southern, south-western and south-eastern part of the municipality over the study period, and this could be due to the enhanced vegetation cover in these areas as it got a key role in determining UHI. In summer, the change in UHI is 1.63 °C. but in winter the change is negative. In Winter, it shows

a reverse trend, and the UHI has decreased by 2.44 °C. The geographical location of the Palakkad gap allows the North-East monsoon to provide rainfall with its impact in lowering the temperature and affects the weather condition of this region, and winter rainfall also enhances the level of water bodies in and around the city.

UHI was found to be higher around central part of the municipality, especially around Nurani, Chandanagar, Meparambu, Vennakkara, Kavilpad, etc. Similar results are reported by other researchers for India. The occurrence of reduced summer UHI has been reported by Shastri et al. (2017). The negative UHI over a majority of urban areas in India during daytime in summer season (pre-monsoon) (MAM), contrary to the expected impacts of urbanisation, was linked with low vegetation in non-urban regions during dry pre-monsoon summers, leading to reduced evapotranspiration (ET), Shastri et al. (2017). Impacts of water bodies and vegetation play a key role in regulating temperature. The areas along tributaries of Bharathapuzha and Malampuzha exhibited comparatively lower UHI. UHI is comparatively low in the southern parts of the municipality where river Bharathapuzha flows. Where there are more settlements and urban impacts are predominant, a positive UHI ensues (Table 23.6).

The drastic and unsustainable modification in land use and land cover is the major causative factor for the sudden rise UHIs. The relatively warmer temperatures in urban areas compared to suburban areas (i.e. UHI) has potential health hazards, such as mortality due to high temperatures and heat waves stress (Raj et al. 2020b, Vijaykumar et al. 2021, UN Report 2019, Rangarajan et al. 2019). As per
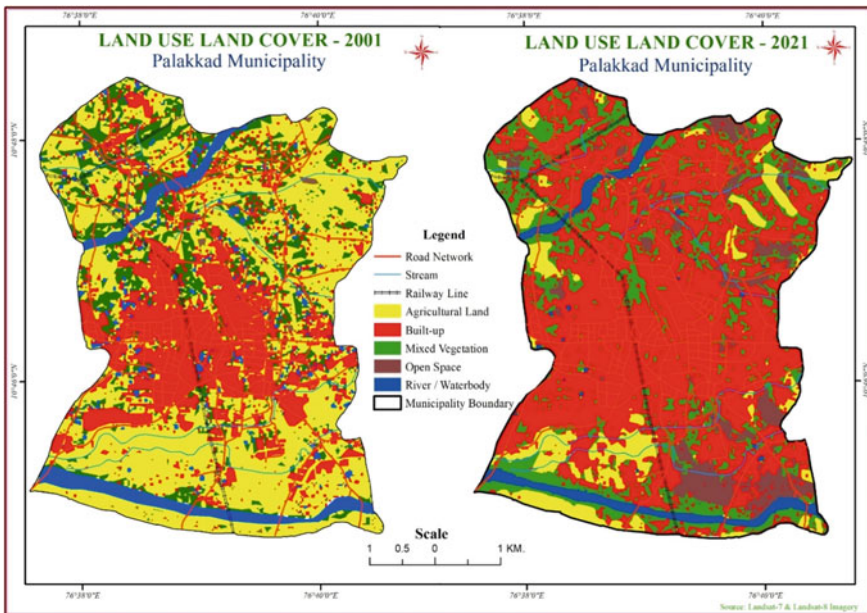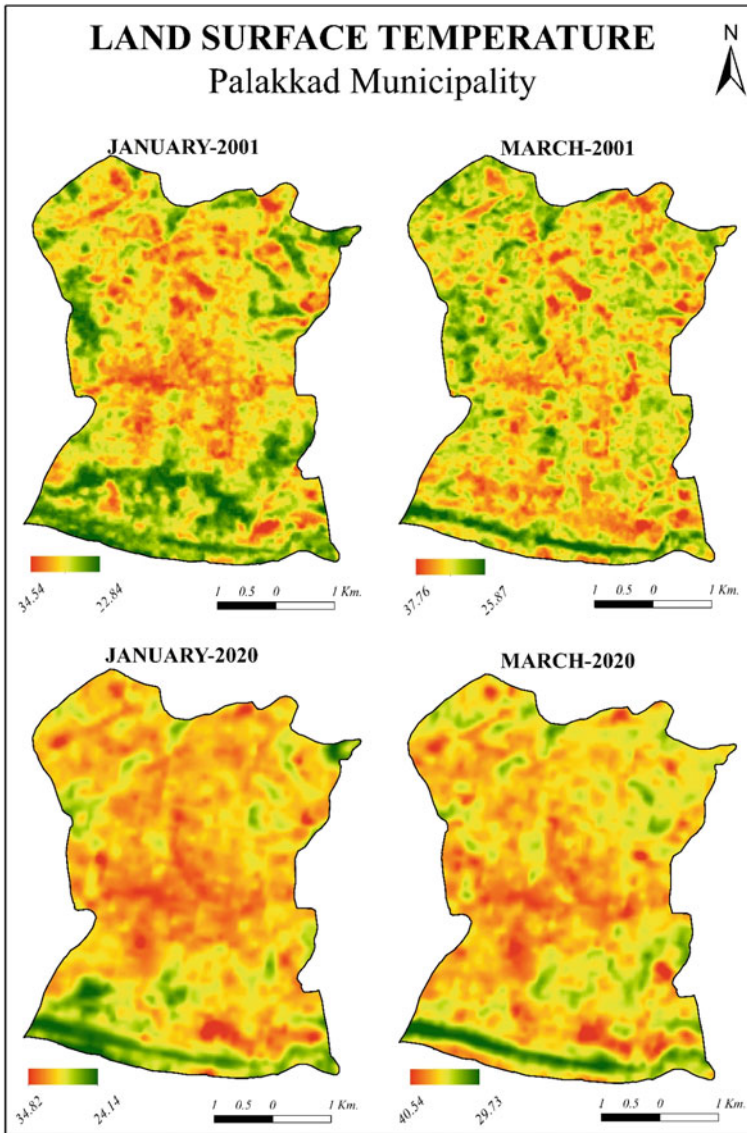

Fig. 23.3 Shows the land use land cover changes. *Source* Landsat 7 and Landsat 8 Imagery

Fig. 23.4 Land surface temperature of Palakkad municipality

the sixth Assessment Report of Inter-Governmental Panel on Climate Change (IPCC 2022), urban heat island effect results from numerous factors: reduced ventilation and heat-trapping due to the close proximity of tall buildings, heat generated directly from human activities, the heat-absorbing properties of concrete and other urban building materials, and the limited amount of vegetation. Rapid urbanisation has exacerbated the effects of global warming in cities (IPCC 2022, Perera et al. 2021,

Table 23.5 Mean LST values for Palakkad municipality

Year	Season	Mean	S.D	Min	Max
2001	Winter (December–February)	27.07	1.32	23.52	31.39
2020	Winter (December–February)	28.35	1.17	24.04	31.93
2001	Summer (March–May)	27.61	1.04	23.19	31.67
2020	Summer (March–May)	29.60	1.10	25.11	33.22
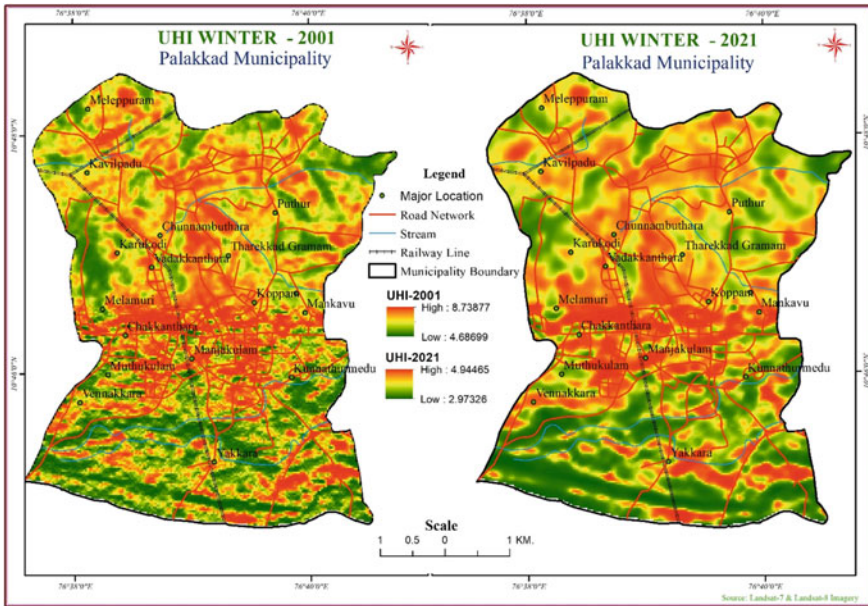
Fig. 23.5 UHI changes during winter in Palakkad municipality

Parsaee et al. 2019, Panmei et al. 2017, Mishra et al. 2018, Jaina et al. 2020, Eric and Kumi-Boateng 2020). Anticipated future urbanisation is likely to augment the projected day and night-time temperatures in cities regardless of the characteristics of the background climate, Brenkert and Malone (2005). UHI in some Indian cities in recent studies was found to be 3.3 °C in Chennai, 8.2 °C in Delhi (Mohan and Kandya 2015), and 2.2 °C in Guwahati (Borbora and Das 2014). A dense network of settlements, construction activities, transport networks, and junctions enhance urban heat islands. Presently, every year is witnessing record-breaking extreme weather events year in Kerala. Especially the urban floods and landslides in Kerala during 2019 has seen some unusual weather activity with rainfall exceeding 50 mm in 2 h has been reported from many places between 8.00 and 22.00 UTC on August 8, 2019 (Mishra et al. 2018). If the year 2019 is any indication of how global warming may continue to impact this area, changes in the cloud structure and kind of strong rainfall events, and heat islands could represent a serious threat to the urban ecosystems,
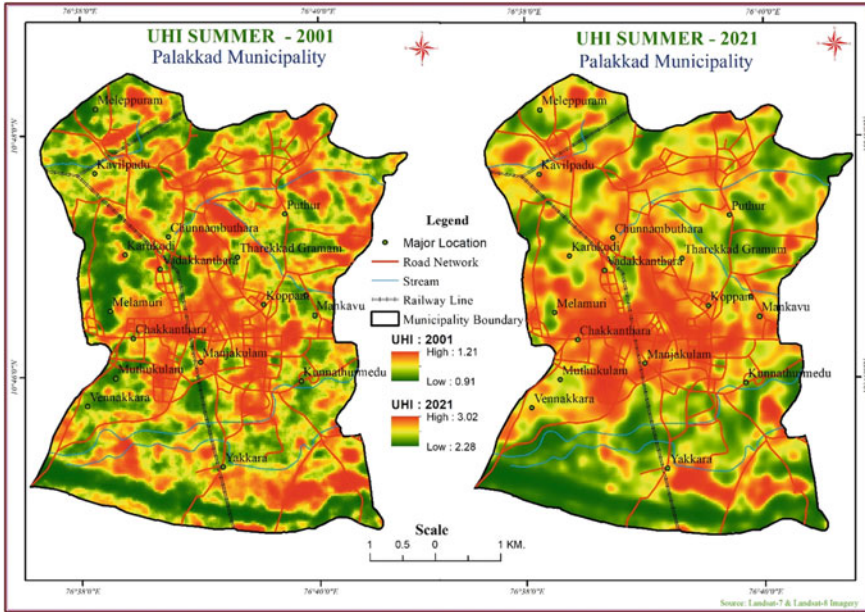
Fig. 23.6 UHI changes during (a) summer in Palakkad municipality

Table 23.6 Descriptive statistics of UHI values for Palakkad municipality

Year	Min	Max	Mean	S.D
Summer-2001	0.91	1.21	1.06	4.01
Summer-2021	**2.28**	**3.02**	2.69	0.20
Winter-2001	4.68	8.73	6.55	0.41
Winter-2021	**2.97**	**4.94**	*4.11*	0.22

which are extremely fragile due to its socio-economic characteristics (Donatti et al. 2020; Hunt and Menon 2020).

Hence, there is a growing concern in India for even intensifying night-time lamination in urban areas for the past one decade, Bose and Chowdhury (2020). India's nationally determined contributions (INDCs) have concentrated mostly on climate change mitigation focusing on adopting greening and afforestation programs, shift to more sustainable renewable energy sources, emission reduction measures, etc. (Aayog 2021). The per capita emission in India is only 1.69 Metric tonnes of CO_2 whereas United States has 17.05 Metric Tonnes of CO_2 emissions. There may be doubling of demand for food grains and animal protein to satisfy growing population demands and similarly demands for ecosystem services in urban areas. Small patches of barren lands and waste lands need to be converted as Miyawaki forests. The self-sustaining Miyawaki forests grow in small patch of lands within two to three years and contribute to the reduction of air and noise pollution, and cools down heat islands. Apart from that, it attracts of local avian wildlife and creates carbon sinks.

Cities in India were facing immigration from rural areas in search of better employment opportunities. However, reverse migration was also seen during the present COVID-19 pandemics (Dutta et al. 2021). A combined impact of weather and heat waves has a considerable impact on the lives of the inhabitants, especially in hot and dry climate zones (Tran et al. 2017). The presence of thick vegetation cover and good climate plays a significant role in regulating heat island effects. An analysis of UHI based on LST derived from satellite observations in Asian megacities shows strong negative associations with the urban normalised difference vegetation index (NDVI) and positive associations with built-up areas (Tran et al. 2006).

Conclusions

This research article aimed to investigate spatio-temporal variations in LULC and LST concerning UHI intensity over Palakkad Municipality, one of the fastest growing/populated/ urbanised districts of Kerala. The results indicated that a significant reduction in vegetated land and water bodies was observed at the expense of built-up areas. In the summer season, the mean LST had increased by 1.63 °C during the study period. The LST outlines indicate that built-up areas under urban expansion exhibited high LST, and there is vast disappearance of the vegetated area near the water bodies (Bharathapuzha) in the municipalities over the study period. Warming is more towards the central and southern side of the Municipality.

Highlights and Way forward

In this chapter, land use land cover change and Urban Heat Island Intensity (UHI) of Palakkad Municipality are dealt with.

- Urban heat island is noted more in the central part of the Palakkad Municipality
- There may be enhanced risks of extreme heat stress and discomfort for the inhabitants living in the centre of the municipality if timely mitigation measures are not taken.
- It is evident from the study that how the high density of settlements and population, lack of natural vegetation/greenness, water bodies and anthropogenic forcing are influencing factors driving UHI impacts.
- The trend of SUHII shows an increase over time (2001–2021) for PKDM. The lost tree coverage must be regained to enhance the cooling effect.
- Further, studies can be conducted to survey the inhabitants' perceptions to validate the outcomes. Apart from that, several drawbacks to this work should not be overlooked. Field-based investigations can be conducted using meteorological instruments like wet and dry bulb thermometers, and swirling hygrometers to substantiate the results derived from remote sensing-derived index were adopted to identify UHI over major the PKDM. The climatic variables and landscape metrics like cover type and albedo can make study furthermore effective, as the factors could have an extensive influence on LST.

Conflict of Interest The authors declare that they have no conflict of interest.

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