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Research Article

Estimation of land surface temperature for Coimbatore District using Landsat imagery

Aravind P*
Department of Soil and Water Conservation Engineering, Agricultural Engineering College & Research Institute, Tamil Nadu Agricultural University, Coimbatore- 641003 (Tamil Nadu), India
Selvakumar S
Department of Soil and Water Conservation Engineering, Agricultural Engineering College & Research Institute, Tamil Nadu Agricultural University, Coimbatore- 641003 (Tamil Nadu), India
Thiyagarajan G
Water Technology Centre, Tamil Nadu Agricultural University, Coimbatore- 641003 (Tamil Nadu), India
Balaji Kannan
Department of Soil and Water Conservation Engineering, Agricultural Engineering College & Research Institute, Tamil Nadu Agricultural University, Coimbatore- 641003 (Tamil Nadu), India
Boomiraj K
Directorate of Open & Distance Learning, Tamil Nadu Agricultural University, Coimbatore- 641003 (Tamil Nadu), India

*Corresponding author. Email: aravindbupathi@gmail.com

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Abstract
The impact of climate change is visually witnessed in the present environment by various natural disasters. This phenomenon of land surface temperature is one of the significant aspects to be estimated for the study of climate change. The increase in Land Surface Temperature (LST) may be due to ongoing developments in the field of urbanization and globalization. The objective of the study was to estimate the increase in the LST in relation to the Normalized Difference Vegetation Index (NDVI) and assess the spatial variation in the LST due to land use/land cover change. The study utilized Landsat 8 data to assess the land-use changes and their relation with LST in one of the main urbanized cities, i.e. Coimbatore district of Tamil Nadu, using Landsat imagery due to the availability of various land cover types by using the mathematical expressions in ARCMAP software. This study compares the LST between 2015 and 2020 to observe the change in the NDVI and LST over a period of 5 years in the Coimbatore district. There was an increase of 1°C in 5 years and the area of high LST had been increased comparatively. The maximum LST was found to be 73°C in 2015, which increased to 74°C in the year 2020 ;and the minimum LST was found to be 15°C in 2015, which increased to 19°C in the year 2020 depicting the ongoing change in the land use of the district. The study findings will help promulgate sustainable urban land-use policies and can be used for mitigating climate change.

Keywords: Climate change, Land surface temperature, RS & GIS, Satellite images

INTRODUCTION

Climate change is one of the important circumstances that we are undergoing now, which is a cause of many of the natural disasters that are impacted by human beings and affect human beings directly or indirectly. This situation makes us think about alternative methods to overcome climate change variations, and in one way, we are trying to safeguard us from the ongoing climate crisis. Climate change could be visually felt from the melting of glaciers, forest fires, an increase in surface temperature, and the global sea level. LST and LULC studies based in India have mainly focused on metro cities and big urban areas (Govind and Ramesh, 2019). The conventional method for assessing surface temperature by meteorological department weather stations and various private weather observation firms is not suitable for hilly topographical areas, which is a manual and time-consuming process. Remote sensing and geographic information system (GIS) methodologies have made it possible to develop models and assess the effects of change in the landscape on urban surface temperature and their micro climate (Sahana *et al*., 2018). These vegetation attributes were used in various models to study surface albedo (Salifu and Agyare, 2012), photosynthesis, carbon budgets (Pandapotan *et al*., 2016), water balance and related processes. However, satellite data are irrespective of the terrain and it is a very feasible process of processing the data in a computerized manner. Various techniques have been established to estimate LST for Urban Heat analysis, Meteorology and Land Cover Dynamic monitoring using brightness temperature (Joshi and Bhatt, 2012).

Land surface temperature (LST) is the temperature of the Earth's surface and is one of the key indicators representing climate change due to urbanization and globalization of the world land surface. LST is a good indicator of climate variability and urban expansion (Mukherjee, F. and Singh,2020). Walawender *et al*. (2014) projected the use of normalized LST to study the spatial distribution of LST in relation to LULC. This can also be related to the increase in the evapotranspiration of the crop leading to the loss of more water from the plant. LST can be estimated through a thermal infrared remote sensing (TIRS) dataset. The algorithm used here is known to be split window algorithm, which uses the two thermal bands located in the atmospheric window between 10 and 12 µm (Nikam, *et al*., 2014). It can measure the apparent temperature of the Earth's surface by calculating the radiant energy exiting the Earth's surface.

LST also plays an important role in increasing the evaporation rate, thereby decreasing the surface water availability and creating a demand in the application of water to crops and making crops wilt, thereby affecting the crop yield of farmers. Crops are a primary factor that influences soil's water balance in the environment by transferring the heat and moisture from the soil surface to the air (Acharya *et al*., 2017). Synoptical and high resolution of the land surface by satellites provide an opportunity to retrieve geophysical parameters like LST, at local to global scale in a spatio-temporally manner (Rozenstein *et al*., 2014). LST is a factor that can be predicted with the help of satellite imagery at the global level with the utmost accuracy. In different time periods, attempts have been made to draw a correlation between LST in UHIs and some land use/land cover (LU–LC) indices (Estoque *et al*., 2016). The LST can be related to the normalized difference vegetation index to have a visual impact on climate change, surface temperature and a decrease in vegetation practices. NDVI is the major indicator of urban climate, which indicates a linear relationship between Land surface temperature and NDVI. This negative correlation between them is valuable for urban climate studies (Guha *et al*., 2018). The objective of this study was to find the change in LST between 2015 and 2020 in the Coimbatore district.

MATERIALS AND METHODS

Study area

Coimbatore District in the state of Tamil Nadu and lies in the GPS coordinates of 11° 0' 16'' N and 76° 57' 41'' E at a mean sea level of 411 m. The Coimbatore district covers an area of 4723 km^2. The average rainfall of this area is approximately 618 mm. The third largest city of Tamil Nadu, Coimbatore, is known as one of the industrialized cities in India. The Coimbatore district is an urban city that is sustainably developing, but the city is severely affected due to enduring climate change and population explosion. More than 55% of the world's population lives in urban areas and it is projected to be more than 68% by 2050 (World Urbanization Prospects, 2019). The district has a major green cover area due to western ghats, which cover the major forest areas in the district. The Coimbatore district comprises the major part of the Nilgiri Biosphere Reserve, with an area of 5520 square km. The Coimbatore district was chosen due to the availability of various land covers like rivers, lakes, hilly terrain, urban settlements, barren lands and agricultural lands, which made to study the behavior of each land cover type in relation to the surface temperature of those areas. The western ghats in the district are home to rivers such as Bhavani, Noyyal, Aliyar and Siruvani, fulfilling the district population's drinking and irrigational water needs. The study area map is visualized in Fig. 1.

Landsat 8 data

Landsat 8 satellite images were downloaded from the United States Geological Survey website, and the interpretation of data for two different dates was performed to compare the LST and NDVI. Two Landsat images from May 2015 and May 2020 were taken to estimate the land surface temperature and NDVI of the Coimbatore District. Landsat 8 satellite images have two different sets of images from the Operation Land Imager (OLI) sensor with nine bands (band 1 to 9) and Thermal Infrared Sensor (TIRS) with two bands (band 10 and 11) (Roy *et al*., 2014). The Landsat 8 images used in this study are shown in Table 1.

Estimation of LST

It can only be observed by comparing the present situation with the past situation (Akhoondzadeh and Saradjian, 2008). LST measurement is the visual observation of the current climate change around us. LST was calculated by applying a structured mathematical algorithm, i.e., the split-window algorithm (Rajeshwari and Mani, 2014). Band 10 images (thermal sensor images) of Landsat 8 imagery from May 2015 and May 2020 were used to obtain the emissivity, radiance and land surface temperature maps of the study area. Band 4 and Band 5 data were used to estimate the normal-

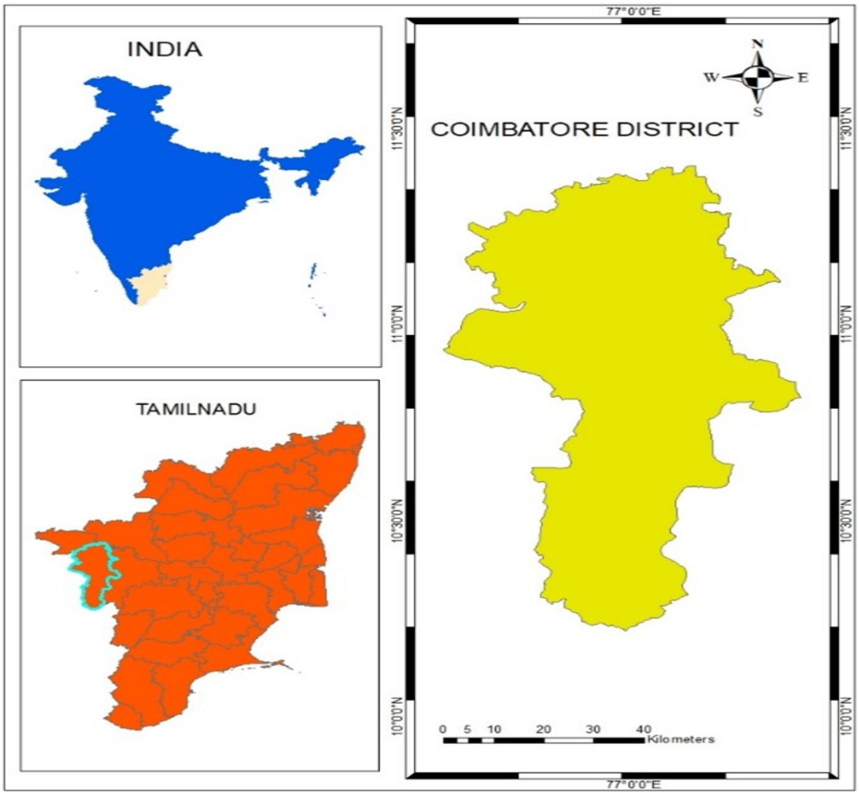

Fig. 1. *Study area map of Coimbatore district*

Table 1. Particulars of Landsat 8 image used in this study

S. No.	Acquisition Date (yyyy–mm–dd)	Solar Elevation Angle (degrees)	Solar Azimuth Angle (degrees)	Cloud Cover in image (%)	Cloud Cover in study area (%)
1	2015-05-05	65.65	76.30	15.9	15.9
2	2020-05-02	65.75	77.85	11.28	11.28

ized difference vegetation index (NDVI) and to observe the vegetative scale pertaining to the LST. LST studies can be performed on a large scale to address the impact of global warming and climate change annually and to implement measures to sustain the temperature for agriculture and all other allied works. These can be directly correlated with the green cover and vegetation of that area (Aryalekshmi *et al.,* 2020).

Methodology

The study area shapefile was loaded in ArcMap software. The Landsat images were loaded to the software interface. The Coimbatore district was delineated and masked to the Landsat data to obtain more accurate readings. The LST calculation can be performed in the raster calculator tool of the ARCMAP software, and the following formulas can be used to describe the LST, NDVI, emissivity and radiance of the study area.

Top of atmospheric spectral radiance

It is the proportion of radiation reflected by the incident solar radiation from the land surface. It can be determined by the multiplication of the rescaling multiple factors (0.000342) of the Band 10 Image with its band 10 and the addition of the Addition rescaling factor (0.10000). We were able to develop a radiance map of the study area.

$$L\lambda = M\mathcal{L} \times Q\ cal + A\mathcal{L} \qquad \text{Eq. 1}$$

Where $L\lambda$ is the top of atmospheric spectral radiance, $M\mathcal{L}$ is Band 10 (multiplicative rescaling factor), $Q\ cal$ is the Band 10 image, and $A\mathcal{L}$ is Band 10 (additive rescaling factor).

Brightness temperature

Brightness temperature can be stated as the microwave radiation radiance moving upwards from the top of Earth's atmosphere. The top atmospheric spectral radiance dataset can be transformed into the top atmosphere brightness temperature by using the thermal constants in the Landsat image metadata file.

$$BT = \frac{K2}{\ln\left(\left(\frac{k1}{L\lambda}\right)+1\right)} - 273.15 \qquad \text{Eq. 2}$$

where K1 and K2 are the TIRS thermal constants and $L\lambda$ is the top of atmospheric spectral radiance.

Normalized Difference Vegetation Index (NDVI)

NDVI is a measure of the vegetation status of the study area and can be measured by calculating the difference of the Band 5 (NIR) and Band 4 (red) images of the TIRS Landsat imagery.

$$NDVI = \frac{(NIR-RED)}{(NIR+RED)} \quad \text{....Eq. 3}$$

$$NDVI = \frac{(Band\ 5-Band\ 4)}{(Band\ 5+Band\ 4)} \quad \text{....Eq. 4}$$

Where:

NIR- DN values of the Band 5 image

RED-DN values of the Band 4 image

Land surface emissivity

It can be stated as the average emissivity of an element of the Earth's land surface, which is calculated from the proportion of vegetation and DN values from the NDVI image of the study area.

PV=((NDVI-NDVI"min")) / ((NDVI "max"-NDVI"min"))^2 .... Eq. 5

Where:

PV-Proportion of vegetation

NDVI-DN values from the NDVI image

$NDVI_{min}$ – Minimum DN values from the NDVI image

$NDVI_{max}$ – Maximum DN values from the NDVI image

$$E = 0.004 * PV + 0.986 \quad \text{....Eq. 6}$$

Where:

E- Land surface emissivity

PV- Proportion of vegetation

0.986 is added as a correction value of the equation

Land surface temperature

LST is the radiative temperature of the surface, which is calculated using the wavelength of emitted radiance, top of atmosphere brightness temperature and land surface emissivity.

$$LST = \frac{BT}{(1+\left(\lambda*\frac{BT}{C2}\right)*\ln(E))} \quad \text{....Eq. 7}$$

Where:

BT- Top of atmosphere brightness temperature

λ - Wavelength of emitted radiance (10.8 for band 10)

E – Land surface emissivity

C_2- 14388 mK

The land surface temperature is the temperature of the Earth's surface that is estimated from Landsat imagery. It is indirectly related to the NDVI of the study area. Higher vegetation will be associated with lower land surface temperature and vice versa. If the emissivity also increases, it may be due to barren lands and built-up lands. The land surface temperature also increases the evaporation rate and decreases the available water for the plants.

RESULTS AND DISCUSSION

Normalized Difference Vegetation Index (NDVI)

The most widely used vegetation measure for global observation of green conditions is the NDVI. NDVI is used to track the dynamics in vegetation and land surface interactions to hydrological variations at large scale levels (Ahmed *et al.*, 2017). The visible portion of the electromagnetic spectrum is well absorbed by healthy plants. An important parameter to measure the status of urban health is land surface temperature. NDVI helps depict the green area of the Coimbatore district. Short waves from the sun have more heat energy so that the green surface will decrease the surface temperature more effectively than the barren land surface. NDVI values range from -1 to 1. A value of zero indicates the presence of urban settlements, while a negative value is an indication of a water body. A positive value closer to one indicates the presence of green cover areas. Therefore, the NDVI directly impacts the LST of the Coimbatore district. The NDVI was estimated for the periods May 2015 and May 2020 to obtain knowledge on the change in the vegetation status of the Coimbatore district. The NDVIs of May 2015 and May 2020 are visualized in Fig. 2 and Fig. 3, respectively. A spatial variation of NDVI depends on factors such as topography, slope, nature of the surface, radiation etc. (Zhan *et al*. 2012).

The values of NDVI during May 2015 ranged from -0.05 to 0.68. In contrast, the NDVI values during May 2020 ranged from -0.05 to 0.63, which depicts that the water bodies, i.e., the negative values have no change over a period of 5 years. In contrast, there was a decrease in the agricultural areas, which can be observed by the reduction in the NDVI values from 0.68 to 0.63. The lower values of NDVI indicate the presence of water bodies which can be seen on the southern side of the study area. Similar values of NDVI were obtained for vegetation in the study conducted in Indonesia by Zaitunah *et al.* (2018). From the NDVI comparison of the Coimbatore district between 2015 and 2020, it was seen that the vegetation intensity and vegetation area decreased, which may be due to the increase in urban settlements and the decrease in the farmers' agricultural activities in those areas. The northeastern part of the Coimbatore district is seen to have a great decrease in the NDVI, which may be due to the ongoing urbanization in the city, and the southern part seems to be developing in vegetation areas. The western part is in the forest range, so there could be highly intense vegetation in those areas. From this observation, the present study can hypothesize that the LST could have increased when compared to May 2015. This shift in the

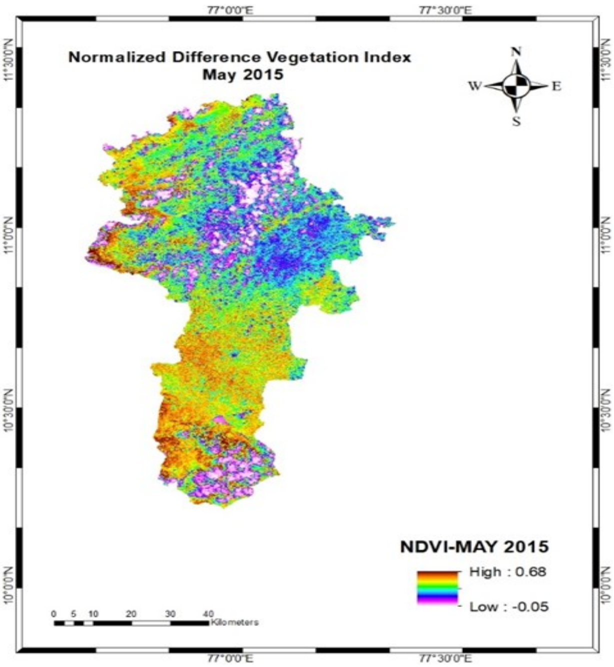

Fig. 2. *NDVI on May 2015 depicting the vegetation status of Coimbatore district*

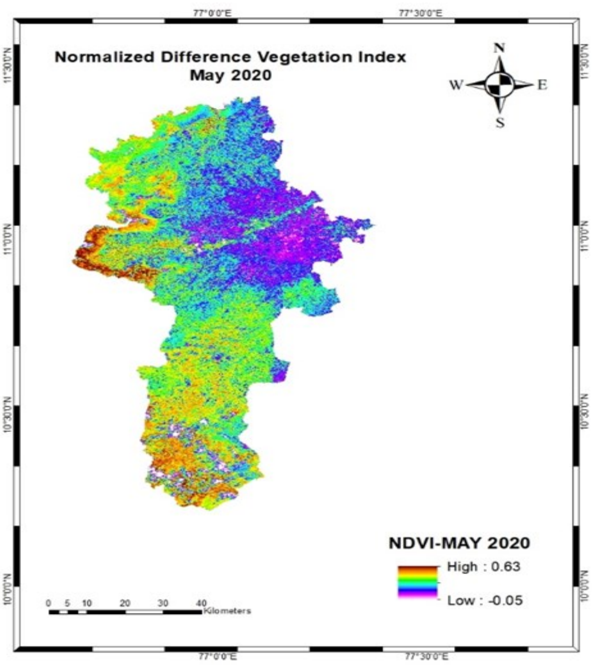

Fig. 3. *NDVI on May 2020 depicting the vegetation status of Coimbatore district*

spatial patterns of the urban areas was due to the developments of industrial, urban migration and Information Technology (IT) based services in the study area. Unplanned infrastructures and unregulated urban sprawl have changed the physical characteristics of the urban cover and the rural areas. There has been a large-scale conversion of agricultural lands into urban residential land use, a common phenomenon in the study area. The increase of built-up land (NDBI) and loss of vegetation cover (NDVI) become a serious problem for the increase in LST (Dai Nguyen *et al*.,2021). These undesirable spatial changes resulted in the loss of green cover and an increase in the impervious layer of the study area. Hence, the study on NDVI and LULC patterns of the study area are helpful for understanding the surface temperature deviations in the Coimbatore district.

Emissivity

Land surface emissivity is the average emissivity of an element of the Earth's surface, which is calculated from the NDVI values of the study area. Surface emissivity does not completely depend on the material but also due to the nature of the surface. Emissivity is defined as the ratio of the energy radiated from a material's surface to that radiated from a black body at the same temperature and wavelength and under the same viewing conditions (Rajendran and Mani 2015). Emissivity changes with the change in temperature of the surface, so the vast change in the land surface temperature can be visualized through the change in the emissivity of the study area. Emissivity is proportional to the temperature. The emissivity of water bodies is constant in comparison with the land surfaces since the emissivity depends on the wavelength of the land surface, the NDVI threshold method (Sobrino *et al*., 2008).

Emissivity was estimated for the periods' May 2015 and May 2020. They are visualized in Fig. 4 and Fig. 5. The emissivity values ranged from 0.986 to 0.99 during May 2015 and May 2020. They seemed to be similar in range, but the areal extent of the emissivity was increased, which can be seen as a spatial change in temperature, and the temperature increase could be minimal in the Coimbatore district. The emissivity was increased in the southern part of the Coimbatore district, which might be due to the increase in the NDVI, so the LST may be low in that part due to the impact of the vegetation.

Land surface temperature

Urbanization is one of the important factors which can modify the local climate and ecology in the study area. The ongoing change in Land use and land cover because of urbanization influenced the energy budget system and caused the development of heat in the land surface in many parts of the district. LST was inversely influenced by vegetation and green cover as vegetation can significantly reduce LST in urban environments and make urban areas less vulnerable to impacts of climate change (Zhou *et al*.2020). The LST was spatially determined over the Coimbatore district, and the variation in LST over 5 years gap was depicted. From Fig. 6 and 7, it can be understood that the minimum temperature in LST of May 2015 increased by 4°C in May 2020 and that the maximum temperature also increased by 1°C.

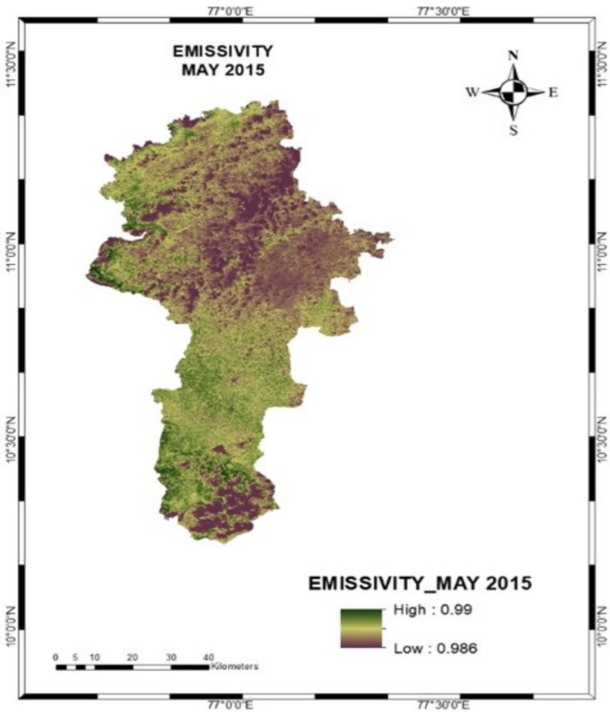

Fig. 4. *Emissivity on May 2015 showing the spatial variation in Coimbatore district*

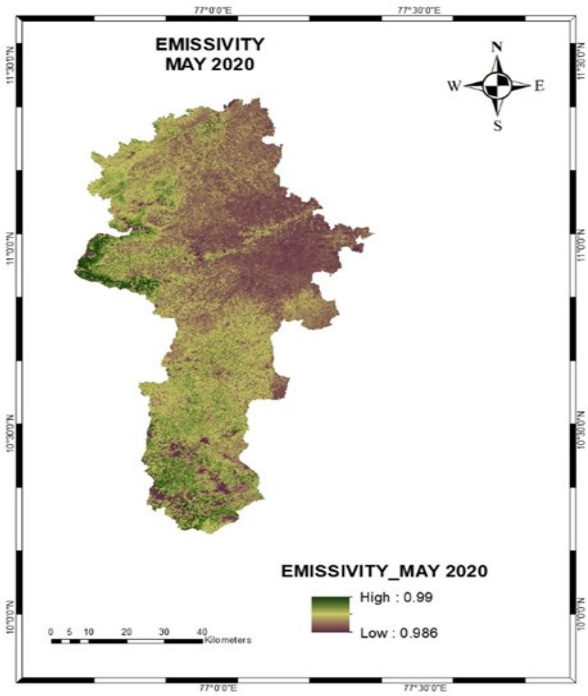

Fig. 5. *Emissivity on May 2020 showing the spatial variation in Coimbatore district*

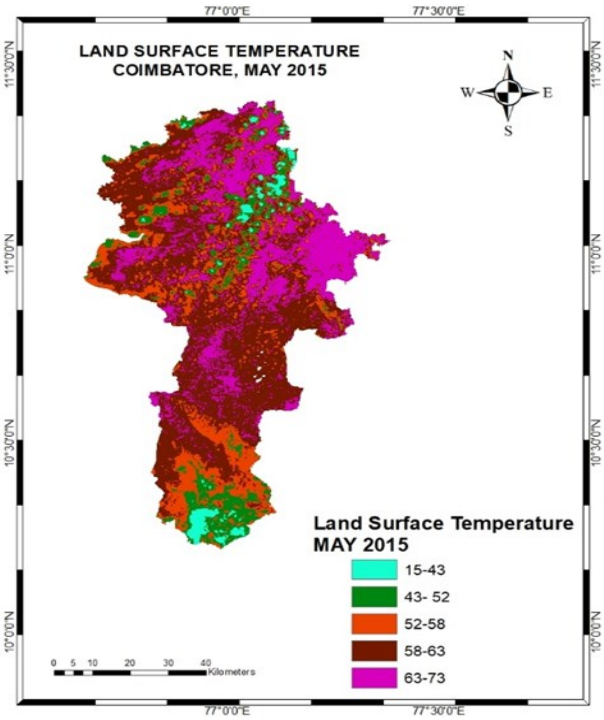

Fig. 6. *LST of May 2015 depicting the spatial variation in Coimbatore district*

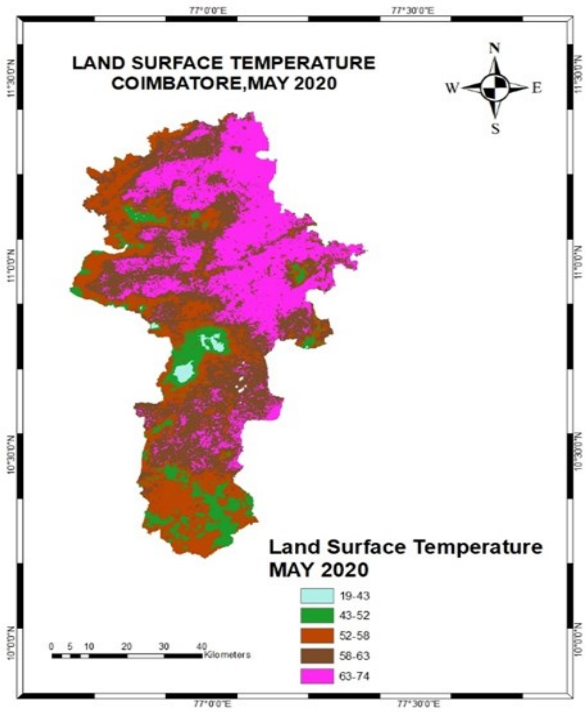

Fig. 7. *LST of May 2020 depicting the spatial variation in Coimbatore district*

The areal extent of the LST of high temperature increased, showing the rate of climate change spatially. The maximum LST was 73°C in 2015 and increased to 74°C in 2020, and the minimum LST also increased from 15°C in May 2015 to 19°C in May 2020. The area of the maximum temperature range increased on the north and northeastern sides of the district, and the area of the minimum temperature range decreased on the southern side of the Coimbatore district. The LST decrease in the central part of the district may be due to the location of hilly terrains. LST obtained over the urban settlements is high and the LST values are comparatively low over the vegetated as well as areas of water bodies. Adulkongkaew *et al.* (2020) found from a study that LST had an increase in suburban and urban areas in recent years in the urban areas of Bangkok. The observed change in the LST of the Coimbatore district was due to the increase in the built-up and urban areas. Most of the lands were converted to barren land, which resulted in the decrease in vegetation area and the change in the LULC of the Coimbatore district. The relationship between LST and NDVI within each LULC type, the relationship is not always linear and may vary depending on the study area and micro climate (Tran *et al*., 2017).

LST may vary seasonally due to the vegetation, water bodies, and the lakes in the district's urban areas, which would result in moderating the surface temperature. In many parts of the world, urbanization is leading to creating urban areas into most vulnerable parts of the environment leading to excessive pollution and health hazards (Mukherjee and Singh, 2020). Numerous lakes present in the urban limits of the Coimbatore city acts as a cooling agent in the local climate of the district even during summer. This vegetation and water cover in the study area played a crucial role in stabilizing the LST in surrounding urban areas and helped in controlling the surface temperature. LST would likely increase in the future, particularly in the middle part of the study area. A gradual increase could be observed in the north and northeastern part of the city due to the ongoing urbanization and decrease in the green cover in the study area. The LST values were in accordance with the values obtained in Thiruvananthapuram district by Rajendran and Mani (2015).

Some agricultural land areas in Coimbatore district were found to have high LST during the period of study, which were left fallow during the summer season. The built-up area recorded a maximum temperature on the impervious surface due to the study area's impervious and built-up land cover. Drying of seasonal rivers and a decrease in the water levels of the lakes in the study area may also result in the variation of LST during summer season. Similar results were presented by Sahana *et al.* (2018) in a study on LST in Mumbai city.

Conclusion

The present study concluded that the land surface temperature increase in the Coimbatore district is happening gradually. From the results, it can also be said that the areal extent of the land surface temperature was increased compared with May 2015, which may be due to the increase in urbanized lands and the decrease in vegetation in many parts of the district. The study showed that the LST depends on the NDVI and LULC of the land surface. Non-evaporating areas showed an increase in the LST due to the lack of vegetation and the drying up of the water body during the study period. This spatial increase in temperature and the increase in the maximum temperature of 1°C and 4°C increase in the minimum temperature in 5 years could impact climate change over the study area.

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Conflict of interest

The authors declare that they have no conflict of interest.

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