MONITORING SUMMER DAYTIME AND NIGHTTIME DECADAL TRENDS OF LAND SURFACE TEMPERATURE OVER THE NATIONAL CAPITAL REGION DELHI

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KEY WORDS: Land Surface Temperature, Decadal analysis, MODIS, Urban Heat Island, night-time, daytime

ABSTRACT:

Urbanization-related growth and development have been recognized as substantial factors in increasing surface temperatures. India's rapid urbanization has exacerbated climate change challenges, particularly the rising Land Surface Temperature (LST) and Urban Heat Island (UHI) phenomena. The study used LST data from the MODerate Resolution Imaging Spectroradiometer (MODIS) to examine decadal variances in LST and diurnal LST variations over the summer months in a study region. We compared the LST values in 2010, 2020, and 2022 with the reference year 2000 by analyzing LST data collected from 2000 to 2022 using geospatial analysis. The study found a significant increase in the LST over a two-decade period, particularly in May and June, with temperature jumps of up to 10 (°C) both during the day and at night. The study also revealed differences in LST patterns between rural and urban regions, with rural areas having a higher daytime LST than urban areas and urban areas witnessing an elevated nighttime LST owing to the UHI impact. Analysis revealed significant differences in LST patterns, with 2020 showing lower surface temperatures due to limited heat released from anthropogenic activities such as industrial operation and vehicular traffic due to the COVID-19 lockdown. However, in the years 2010 and 2022, the study observed a significant increase in LST during the summer months both during the day and at night. These findings provided useful insights for urban development and planning and contribute to the implementation of measures aimed at reducing heat-related risks and improving the well-being of urban residents.

1. INTRODUCTION

In recent decades, urban climatology has placed an increased emphasis on the study of surface temperature due to its significant influence on the functions of the earth and all living organisms (Masson-Delmotte et al., 2021). Land Surface Temperature (LST) is a vital variable in climate and environmental studies. The researchers observed that LST increases over time due to climate change (Wang et al., 2021). However, in urban areas, factors such as urbanization, industrialization, and anthropogenic activities contribute to additional temperature increases due to the dense population and associated heat emissions (Kim et al., 2022).

According to NASA researchers, the average global temperature has risen by at least 1.1 (°C) since 1880 (Hansen et al., 2020). The majority of the warming happened after 1975, at a rate of about 0.15 to 0.20°C each decade (Hansen et al., 2020). Likewise, the researchers examined different global metropolitan clusters from 2002 to 2021 and they discovered that the average surface warming trend of the globe is 0.50K each decade which is 29% greater than the rural trend (Liu et al., 2022). However, the trend varies depending on the city's climatic zone and level of urbanization (J. Yang et al., 2021; Q. Yang et al., 2021). In the planning of heat stress mitigation measures, it is crucial to conduct a thorough analysis of a city's temperature.

Delhi and its surrounding satellite towns are identified as hotspots for rising temperatures in India. The complex urban configuration of this region (Prathiba & Jain, 2021), characterized by rapid urbanization, pollution, and geographical location contribute contributed to the significant increase in temperatures (Kaur & Somvanshi, 2022). The high population density, urbanization, and industrialization in Delhi exacerbate heat-related problems. Rising temperatures have implications like increased heat-related illnesses, higher energy demands for cooling, and environmental challenges (Dahl et al., 2019). Efforts are being made to mitigate these issues through strategies like developing green spaces, promoting energy-efficient buildings, improving public transportation, and reducing air pollution (Bowler et al., 2010; Santamouris, 2014). Addressing these challenges is crucial for the well-being and sustainability of the population in these regions.

The combination of climate change, population growth, and urbanization has led to higher LST in many regions (Guo et al., 2022). Rising global temperatures have also increased the frequency and duration of heat waves, which have severe impacts on human health, infrastructure, and ecosystems. The urban heat island effect worsens these heat waves in cities (Kearl et al., 2023). This rising LST and increased heat waves pose significant risks to vulnerable populations, strain energy systems, and increase energy consumption.

Numerous studies have analyzed the temporal and seasonal changes in LST and Surface Urban Heat Island (SUHI) effects, particularly concerning urban dynamics, population growth and land cover change (Dahl et al., 2019; Dang & Kim, 2023; Xu et al., 2010). Though, there were very limited studies that examined the decadal shifts in surface temperature and the day and night LST variation. Estimating the decadal LST shift, specifically during the summer months, and analyzing the changes in diurnal LST variation is crucial for urban planning and heat mitigation strategies.

Investigating the periodical change in LST provides valuable insights into the long-term trends and temperature patterns of the study area (Siddiqui et al., 2021), which helps to understand the impact of global (climate change) and local parameters

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https://doi.org/10.5194/isprs-archives-XLVIII-1-W2-2023-1491-2023 | © Author(s) 2023. CC BY 4.0 License.

(urbanization, industrialization, and anthropogenic activities) on surface temperatures over time. This information on changing patterns in surface temperature helps planners and policymakers in future urban planning and sustainable development. This investigation also helps scientists and researchers to gain a deeper understanding of the thermal dynamics and energy distribution in urban and rural environments (Chen et al., 2017). This knowledge is critical for developing targeted interventions to mitigate the UHI effect and manage heat stress in cities.

This study aims to assess the decadal shifts in LST during the summer months and investigate the changes in diurnal LST variation in Delhi and the nearby satellite towns from 2000 to 2022. The specific objectives of the study include:
1. Assessing the changes in summer daytime and nighttime LST values for the years 2010, 2020, and 2022 compared to the reference year of 2000.
2. Analysing the diurnal variation in LST by comparing the differences between daytime and nighttime LST values for each study year.

We collected the daily daytime and nighttime remotely sensed LST data from the MODerate Resolution Imaging Spectroradiometer (MODIS) sensor at a resolution of 1 km from 2000 to 2022 and the decadal change was analyzed for the years 2010, 2020, and 2022 by keeping 2000 as the base reference year (Anniballe et al., 2014; Mohammad et al., 2019). A cloud-based platform, Google Earth Engine (GEE), was used to collect and calculate the monthly /seasonal data averages (Bechtel et al., 2019)

The study is conducted to address the increasing emphasis on the study of surface temperature in urban climatology due to its significant impact on Earth's functions and living organisms. With the global rise in temperature and the influence of urbanization, understanding the changes in LST and diurnal temperature patterns is crucial for effective heat stress mitigation and urban planning. The findings of this study can be applied in urban planning and climate adaptation strategies to mitigate heat stress and enhance the thermal comfort of urban dwellers during summer. The results can inform the development of targeted measures to reduce casualties during peak heat waves, manage the UHI effect, and optimize urban design for sustainable and resilient cities. Additionally, the study contributes to scientific knowledge on the impacts of urbanization and anthropogenic activities on local climate dynamics, supporting evidence-based decision-making for climate change mitigation and adaptation policies.

2. METHODOLOGY

2.1 Study area

The selected study area encompasses the National Capital Territory (NCT) of Delhi, along with surrounding suburbs and satellite cities such as Dadri, Gurugram, Faridabad, Ghaziabad, and Meerut. The area is characterized by diverse land cover features such as urban, vegetation, dense vegetation, water body, fallow land and hilly terrain (Palanisamy, P.A., Jain, K., Bonafoni, 2023). Figure 1 displays the location map of the study area. Spanning over 8602.62 square kilometers, the study area is situated between latitudes 28.155N and 29.256N, and longitudes 76.83E and 77.895E.

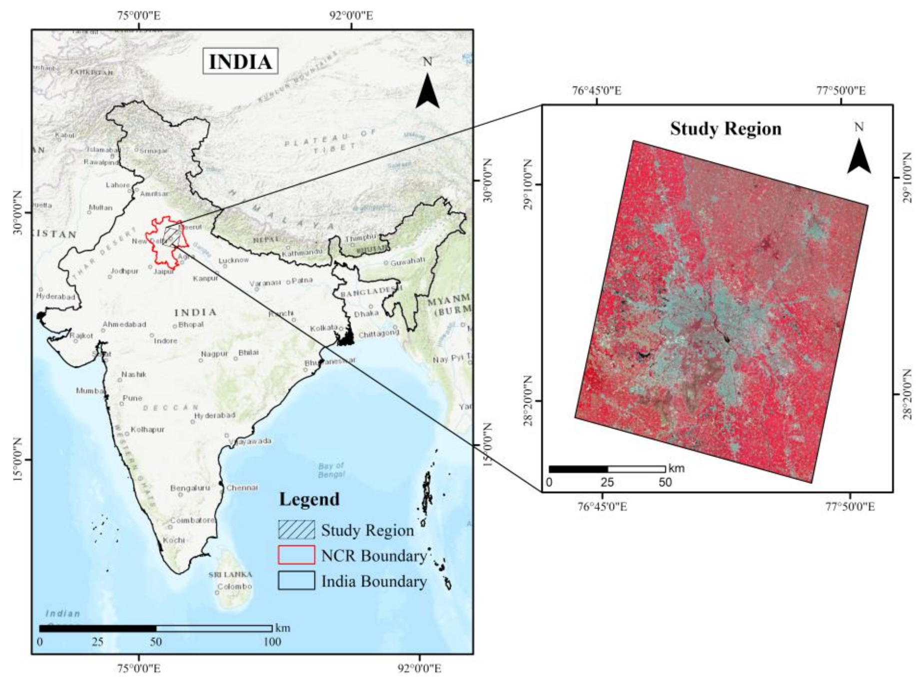


Figure 1. Geographical location of the study area map

The climate of the region exhibits characteristics of both monsoon-influenced humid subtropical (Köppen climate classification Cwa) and semi-arid (Köppen climate classification BSh) climates (Naga et al., 2022). This results in considerable variations in temperature and precipitation between the summer and winter seasons. The summer season in the study area typically starts in early April and lasts until the middle of June. The peak of heat occurs in late May and early June. Additionally, the geographical location of Delhi and its surrounding towns also contributes to the high temperatures. The region is in the northern part of India, which experiences extreme weather conditions. During the summer months, hot winds from the nearby Thar Desert and the lack of significant water bodies contribute to the heat in the region (Chatterjee & Vasudevan, 2015).

2.2 Data used

For this study, daily day, and night LST data from MODIS (MOD11A1) products with a spatial resolution of 1 km spatial resolution were collected for the years 2000, 2010, 2020, and 2022. The data collection was particularly focused on March, April, May, and June, which correspond to the summer season. The daily LST data for each of these years and months were collected and processed in the Google Earth Engine (GEE) platform. Based on the obtained data, the seasonal average value of the day and night LST for the selected months was calculated. This analysis involves aggregating the daily LST values and deriving the average temperature for each specific season and period. The utilization of the GEE platform enabled efficient data acquisition, storage, and processing. GEE provides cloud-based computing capabilities, that enable researchers to access and analyze large-scale geospatial data such as MODIS LST in a convenient and scalable manner.

2.3 The decadal shift in Day and Night LST

Figure 2 shows the analytical framework of this study. To assess the decadal shifts in day and night LST, the study focused on the summer months of March, April, May, and June for the years 2000, 2010, 2020, and 2022. These months were selected to capture the peak heat period when temperatures are typically the highest.

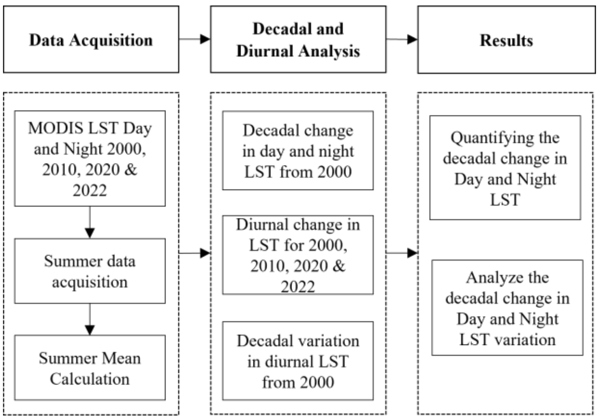
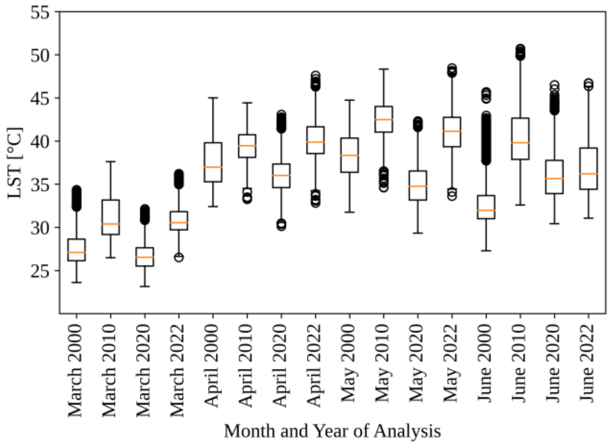


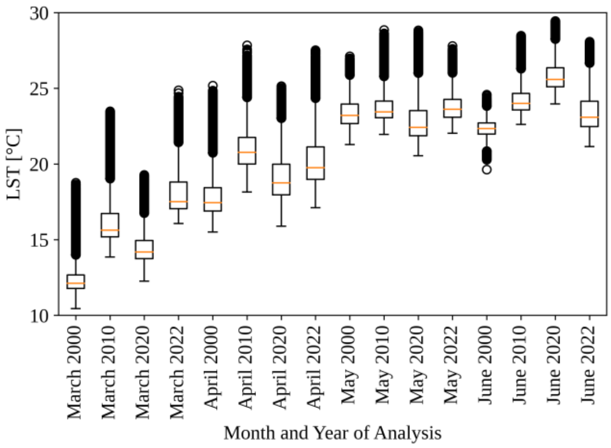
Figure 2. The framework illustrates the technique used in the present study to analyze the decadal shift in LST.

The study calculated the average LST values for both daytime and nighttime during these summer months for each year. Next, the summer average LST values for daytime and nighttime in 2010, 2020, and 2022 were compared to the corresponding average LST values recorded in the reference year of 2000. By calculating the difference between the LST values of each year and the LST values in 2000, the study determined the magnitude of the shift in LST for both daytime and nighttime conditions.

The box plots in Figure 3a and Figure 3b provide an overview of the daytime and nighttime. LST during the summer months of 2000, 2010, 2020, and 2022. Remarkably, the year 2020 stands out with the lowest LST values compared to the other years. This notable decrease in LST can be primarily attributed to the impact of the COVID-19 lockdown measures (Piracha & Chaudhary, 2022). The restrictions imposed during the pandemic resulted in a significant reduction in industrial and anthropogenic activities, leading to decreased heat emissions and subsequently lower surface temperatures. Among the four summer months examined, June and May recorded the highest LST values, with daytime temperatures exceeding 50 (°C) and nighttime temperatures peaking around 30 (°C).



(a)



(b)

Figures 3a and 3b. depict the day and night time LST over the summer months of the selected study year.

2.4 Diurnal LST Variation and its Shift

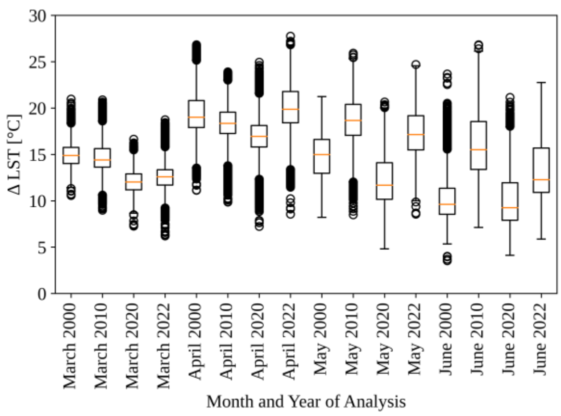


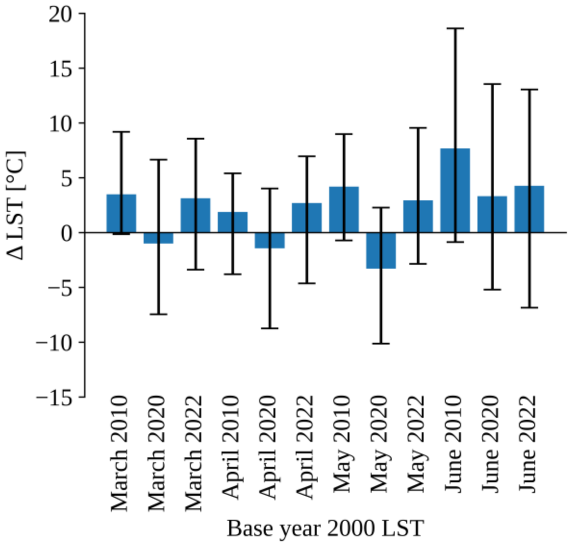
Figure 4. Illustrates the variation in LST between day and night during the summer months of the selected investigation year.

The box plot (Figure 4) represents the difference in day and night LST of the summer months of 2000 2010, 2020, and 2022. In March, the LST difference between day and night was approximately 15 (°C). This difference increased to around 20 (°C) in April, with the maximum LST difference observed in April being close to 30 (°C).

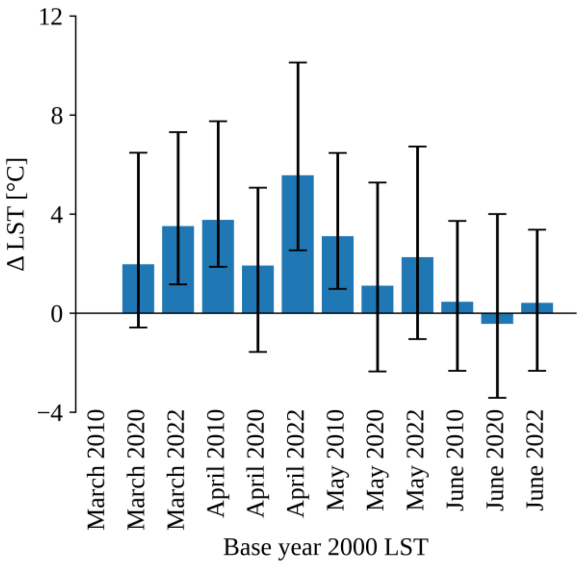
3. RESULTS AND DISCUSSION

3.1 Comparative Analysis of Decadal Summer Day and Nigh LST

Figures 5a and 5b present bar chart that showcase the average changes in LST during the daytime and nighttime for the years 2010, 2020, and 2022, in comparison to the reference year of 2000. The error bars in the graphs indicate the range of minimum and maximum values of the LST changes observed.



(a)



(b)

Figures 5a and 5b. Depict bar chart that illustrates the difference in LST between the base year 2000

The analysis of daytime LST during the summer months reveals that June exhibited the maximum variation. Specifically, in June 2010 compared to 2000, there was a substantial increase in LST, with a growth of approximately 20 (°C). The average change in LST during this period was around 10 (°C). Furthermore, it is noteworthy that several pixels within the study region experienced a significant increase of over 15 (°C) in daytime LST compared to 2000. Additionally, nighttime LST approached a rise of approximately 10 (°C) during this period. Furthermore, the higher temperatures observed in June and May emphasize the severity of heat stress during those months, with implications for human health and urban planning.

Similarly, the analysis reveals interesting patterns for the year 2020 compared to 2000. In March, April, and May, the mean LST values of 2020 fall below those of 2000. However, in June, there is a rise of approximately 4 (°C) in mean LST compared to 2000. In contrast, the nighttime LST values in 2020 exhibit a different trend. The mean nighttime LST for June 2020 shows a negative value, indicating a decrease compared to 2000. On the other hand, the mean nighttime LST values for the other months (March, April, and May) are positive, suggesting an increase compared to 2000.

These observations highlight the variations in LST patterns during different months of the year. The decrease in mean daytime LST during the early months of 2020, followed by a rise in June, may be influenced by various factors such as weather patterns, vegetation cover, and atmospheric conditions. Similarly, the variations in nighttime LST indicate the complexity of factors affecting temperature changes during different times of the day.

In 2010, based on Indian weather history records, there was minimal precipitation observed between March to May. However, in June, a precipitation value of approximately 0.2 was recorded. In contrast, in 2022, noticeable precipitation was observed throughout the study period, with the maximum precipitation value in June reaching around 1.7. The study area consisted of various land cover types, with vegetation being the dominant cover, followed by urban areas. Even within the urban boundary, a noticeable amount of vegetation was present.

From this information, it becomes evident that the lower precipitation in 2010 resulted in reduced vegetation, which subsequently contributed to higher daytime and nighttime LST compared to 2022. The presence of vegetation helps to regulate temperatures by providing shade and undergoing evapotranspiration, which aids in cooling the surrounding environment (Zawadzka et al., 2021). Therefore, the higher vegetation cover in 2022 likely contributed to lower LST values compared to 2010.

These findings emphasize the important role of precipitation and vegetation in influencing LST patterns and highlight the need to consider the interactions between climate, land cover, and surface temperature in comprehensive studies of urban climatology.

3.2 Decadal change in Day and Night LST

The study observed that rural regions exhibited higher LST during the daytime compared to urban areas, while urban areas had higher LST during the nighttime. This difference can be attributed to the cooling capacity of rural regions, resulting in lower daytime temperatures. The landcover map of the study region was referred from our previous study (Palanisamy, P.A., Jain, K., Bonafoni, 2023).

The comparison of average daytime LST between 2010 and 2000 revealed that rural regions experienced a notable increase of more than 5 (°C), with some areas showing an increase of up to 8.12 (°C). In contrast, a few portions of urban regions exhibited an increase of more than 5 (°C), reaching up to 5.31 (°C), in nighttime LST, shown in Figure 6. In 2022, a group of pixels with a land cover type of hilly terrain and urban exhibited a decrease of around 2 (°C) in daytime LST compared to 2000.

However, the maximum increase reached 6.64 (°C), which was lower than the maximum increase observed in 2010. On the other hand, nighttime LST exhibited a rise of around 6 (°C), approximately 0.5 (°C) higher than in 2010.

In 2020, as a result of the COVID-19 lockdown, daytime LST values decreased by up to 5.6 (°C), indicating a significant reduction in surface temperatures. However, there was no significant decrease observed in nighttime LST during this period. The lockdown measures resulted in lower surface temperatures during both day and night, reflecting the impact of reduced anthropogenic activities and decreased emissions on urban heat (Piracha & Chaudhary, 2022).

The study also highlighted significant surface temperature increases in both daytime and nighttime between 2010 and 2022. During the daytime, rural regions experienced higher LST due to lower vegetation cover and increased sunlight exposure, while urban areas displayed higher LST during the nighttime, indicating the presence of the UHI effect. Expansion of the city was also associated with noticeable increases in nighttime LST on the outskirts.

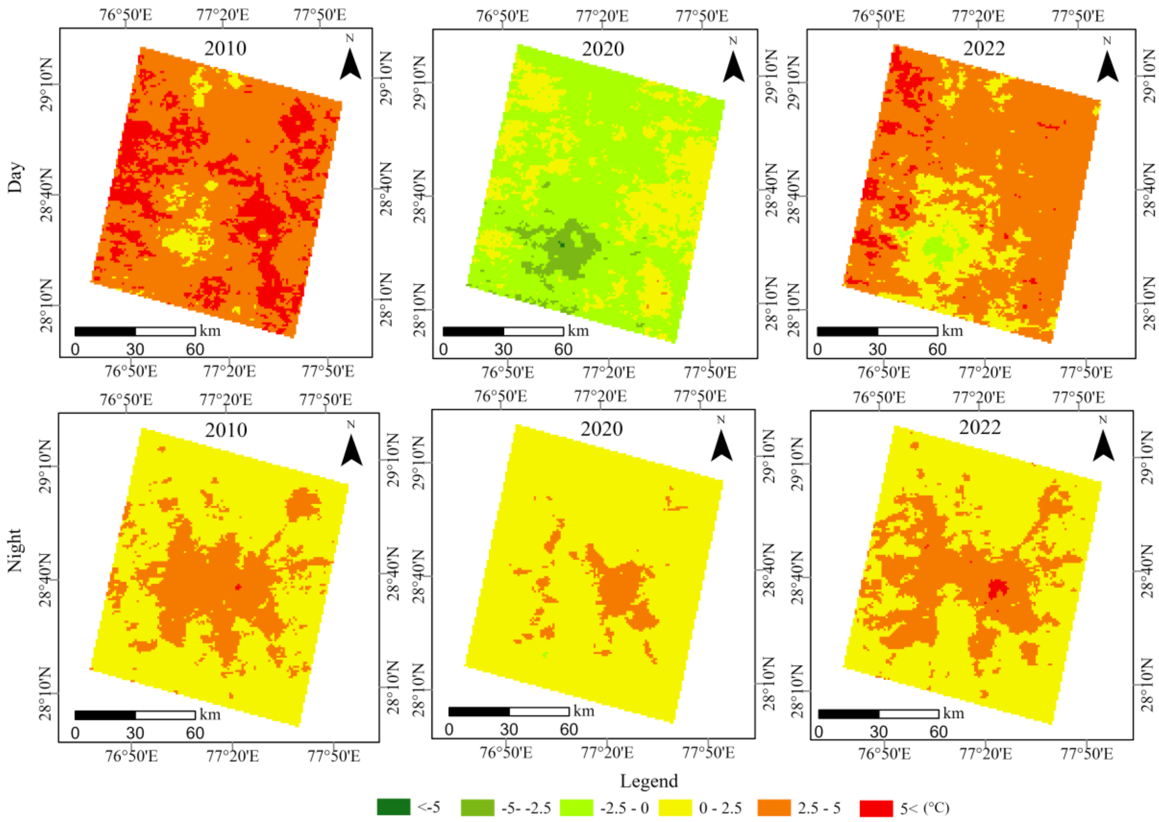


Figure 6. The figure depicts the decadal shift in Day and Night LST for each year compared to 2000 (corresponding year – 2000). The image is categorized using a threshold of Δ LST (°C) 2.5.

3.3 Variation in Day and Night LST

The study examined the decadal shift in the day and night Land Surface Temperature (LST) variation for each month from 2000, as shown in the bar graph in Figure 8. The analysis revealed interesting results regarding the average difference in diurnal variation over the years compared to 2000.

For March and April (excluding April 2022), the average difference in diurnal variation decreased with the years, indicating a reduction in the temperature gap between day and night. However, for May and June, the average difference increased, except during the years affected by the COVID-19 pandemic, where a decrease was observed in May and June.

The decadal diurnal variation shift of June 2010 exhibited the highest mean difference of approximately 5 (°C), with the maximum difference reaching around 18 (°C). These findings highlight the changing patterns of diurnal temperature variations over the years and the influence of various factors, including climatic conditions and anthropogenic activities.

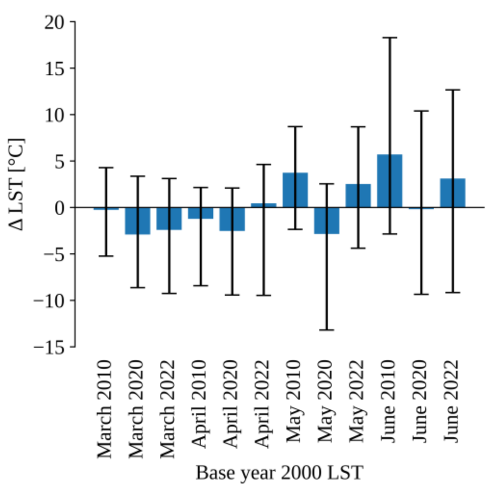


Figure 7. display bar graphs illustrating the difference in diurnal LST variation compared to the base year of 2000.

Figure 9 provides a geographical distribution of the shift in diurnal variation. The study yielded interesting results, indicating that the diurnal variation increased over the years in rural regions compared to urban regions. In many urban pixels, there was a decrease observed in LST variation during both daytime and nighttime as the years progressed.

These findings highlight the contrasting patterns of diurnal temperature variations between rural and urban areas. The increased diurnal variation in rural regions may be attributed to factors such as changes in land cover, vegetation, and meteorological conditions. On the other hand, the decrease in LST variation in urban areas could be influenced by the urban heat island effect, which leads to a more consistent and elevated nighttime temperature due to the thermal properties of built-up environments.

Overall, in the daytime, rural regions tend to have higher LST than urban areas, primarily due to the presence of vegetation cover in non-urban areas (Mohammad et al., 2019). Vegetation helps to absorb solar radiation and undergoes the process of evapotranspiration, which aids in cooling the surface. In contrast, urban areas with higher impervious surface coverage, such as concrete and asphalt, experience reduced evapotranspiration and limited cooling. Conversely, during the nighttime, urban areas exhibit higher LST compared to rural regions. This is primarily attributed to the UHI effect. The UHI effect occurs due to the presence of impervious surfaces and limited green spaces in urban areas. These factors contribute to the retention and re-emission of heat during the night, resulting in elevated nighttime temperatures. The reduced cooling capacity of urban areas and the presence of trapped heat from anthropogenic activities, such as industrial processes and vehicular emissions, exacerbate the UHI effect.

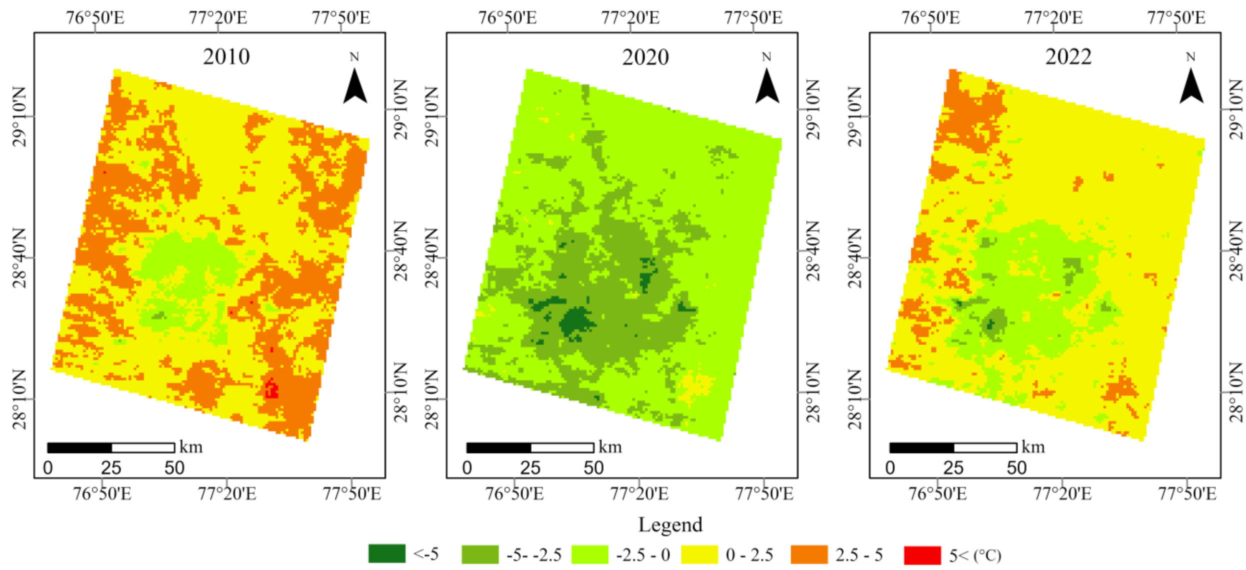


Figure 8. The map shows the decadal shift in diurnal LST (°C) variation for each year compared to 2000 (corresponding year – 2000).

4. CONCLUSION

In the investigation period 2000-2020, it was observed that the urban core temperature increased significantly in May and June. Daytime LST rose by up to 10 (°C), while nighttime LST increased by up to 6 (°C). These results underscore the urgency of prioritizing the planning and execution of effective measures to alleviate future heat stress. The assessment of the LST shifts provided important insights into the temporal patterns and trends of surface temperature changes in the study area. By comparing the LST values between the reference year and subsequent years, we were able to identify and assess the magnitude of the decadal shifts in both daytime and nighttime temperatures. This assessment of LST decadal shifts helps in understanding the long-term changes in surface temperature and their impact on the local climate. By focusing on the summer season, when heat stress is at its peak, the study provides important information about changing surface temperature patterns during the hottest periods of the year. Considering multiple years is crucial as antecedent weather patterns can influence the results. By analyzing a range of years, we can capture the variability and trends in temperature patterns over time, enhancing our understanding of climate dynamics and their impact. It is essential to develop specific approaches that target both daytime and nighttime heat separately, as surface temperatures exhibit diurnal spatial variability. Comprehensive planning is vital to mitigate the adverse consequences of urban heat.

ACKNOWLEDGEMENTS

The authors express their gratitude to the Indian Institute of Technology, Roorkee, India, and the Commonwealth Scholarship Commission, UK for their financial support to Prathiba A Palanisamy to carryout this work at Cranield University, UK, as part of the Commonwealth Split-site Scholarship.

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