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Temporal Analysis of Land Surface Temperature Variations in Gandhinagar city, Gujarat, India during 2003–2020 using satellite data

Neha Nandkeolyar[1]*, Anurag Kandya[2], Viral Patel[2], Shubham Kela[2]

[1] Government Arts and Science college, Harij, Patan
[2]Department of Civil Engineering, Pandit Deendayal Energy University, Gandhinagar

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Abstract - *This study investigates the temporal and spatial variations of Land Surface Temperature (LST) in Gandhinagar, Gujarat, over an 18-year period (2003–2020) using satellite-based observations to understand the thermal impacts of urbanization. The findings reveal a contrasting trend in LST dynamics, with a* ***decrease in daytime LST*** *at a rate of* ***0.05°C/year*** *and an* ***increase in nighttime LST*** *at a rate of* ***0.07°C/year****, which is a typical characteristic of urban heat island effects. Daytime LST was observed to vary between* ***40°C and 43°C****, while nighttime LST ranged from* ***20°C to 22°C*** *during the study period. Spatial analysis revealed a distinct longitudinal thermal stratification for daytime LST by 2020, with the* ***lowest temperatures recorded in green-covered areas*** *such as* ***Indroda Park, Punit Van****, and* ***Akshardham Temple****, emphasizing the significant cooling effect of vegetation. In contrast, industrial zones in the* ***GIDC area on the western side*** *consistently exhibited higher daytime temperatures due to impervious surfaces and urban activity. Nighttime LST, on the other hand, showed a progressive concentration of higher temperatures in the* ***central zone of the city****, attributed to the thermal inertia of densely built-up areas with limited vegetation. These results highlight the critical role of urban structures and declining green cover in shaping the city's thermal environment. The study underscores the need for climate-sensitive urban planning, recommending measures such as expanding green spaces, enhancing vegetation, using reflective building materials, and implementing sustainable urban design practices to mitigate thermal challenges. By providing a detailed understanding of LST dynamics in Gandhinagar, this research offers valuable insights for policymakers and urban planners to address urban heat islands and improve urban livability. It also emphasizes the importance of long-term monitoring of urban thermal environments to inform sustainable and adaptive urban development strategies.*

Key Words**: Land Surface Temperature, MODIS, Gandhinagar, Heat Islands, Urban Planning**

1. Introduction

The world is grappling with a continuous rise in global temperatures, a phenomenon primarily attributed to rapid urbanization (Mathew et al., 2018). Urbanization, characterized by the transformation of natural landscapes into built environments, has been identified as a significant contributor to environmental changes on a global scale. This transformation alters the physical and thermal properties of land surface materials, leading to various environmental challenges such as global warming, urban heat islands (UHIs), air pollution, and ecological degradation. These changes adversely impact the quality of life and comfort of urban populations, necessitating urgent attention and intervention (Kandya & Mohan, 2018; Mathew et al., 2016; Mohan & Kandya, 2015).

Among the myriad consequences of urbanization, changes in **land surface temperature (LST)** are of critical concern. LST is a measure of the effective radiating temperature of the Earth's surface, playing a pivotal role in regulating surface heat and water exchange with the atmosphere. The phenomenon of urban heat islands, which describes elevated temperatures in urban areas compared to their rural surroundings, is intricately linked to changes in LST. The increase in impervious surfaces, such as concrete and asphalt, and the decline in vegetative cover contribute to significant alterations in LST patterns (Gohain et al., 2020). The measurement of LST has become a vital tool for understanding urban thermal dynamics and their environmental implications. It can be assessed through ground-based methods, such as handheld radiation thermometers, or via satellite and aircraft-based sensors that measure thermal radiance from the land surface. Satellite-based methods, in particular, have gained prominence due to their ability to provide large-scale, consistent, and long-term observations. Using thermal infrared (TIR) spectral channels, satellite data enables the derivation of LST values over expansive areas while accounting for atmospheric attenuation effects (Eleftheriou et al., 2018).

Urbanization is particularly relevant to cities in rapidly developing regions like India, where urban expansion has been occurring at an unprecedented pace. In this context, the capital city of Gujarat, **Gandhinagar**, serves as a compelling case study. Gandhinagar, designed as a planned city in the mid-20th century, has experienced significant urban growth over recent decades. The city's transformation, driven by infrastructural development and population growth, has likely impacted its thermal environment, with implications for both the environment and public health.

The use of satellite-derived LST data offers a unique opportunity to investigate the spatial and temporal dynamics of temperature changes in Gandhinagar. By examining daytime and nighttime LST over an 18-year period (2003–2020), this study seeks to understand how urbanization has influenced the thermal landscape of the city. The study will bring out the interplay between urban expansion and thermal patterns, offering a comprehensive view of urban thermal dynamics. The findings of this study will have significant implications for urban planning and governance. Understanding the changing LST dynamics of Gandhinagar will not only reveal the spatial magnitude of urbanization but also provide actionable insights for policymakers and civic administrators. These insights can guide the implementation of mitigation measures aimed at reducing the adverse impacts of rising temperatures and urban heat islands. Moreover, this research aligns with global efforts to address urban environmental challenges in the context of climate change. The analysis of LST changes contributes to the broader discourse on sustainable urbanization by emphasizing the need for climate-sensitive planning and design. As cities continue to expand, integrating thermal environment considerations into urban development plans will be crucial for fostering resilient and livable urban spaces.

With the background, the present study is undertaken that focuses on the temporal analysis of LST variations in Gandhinagar, Gujarat, using remotely sensed satellite data from 2003 to 2020. By exploring the dynamics of daytime and nighttime LST, the research aims to uncover the thermal consequences of urbanization in a rapidly growing city. The insights gained from this analysis will inform strategies to mitigate the impacts of rising temperatures and urban heat islands, ultimately contributing to a healthier and more sustainable urban environment for the residents of Gandhinagar.

2. STUDY AREA

The present study is done over the 'Green city Gandhinagar' which spreads around 61.55 km^2. Fig. 1 displays the satellite imagery of the study area while Table 1 contains the prominent locations of the city representing the different land-uses/ land-covers.

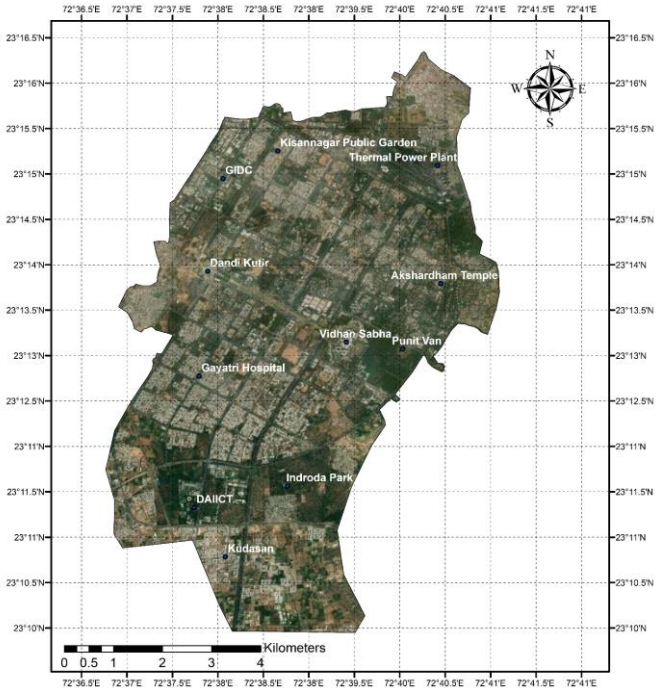

Fig -1: Study area – Gandhinagar city Map

Table -1: Study area with Land-use/Land -cover

Locations	Land-use/Land-cover
Dandi Kutir	Medium built-up area
Thermal Power Plant	Industrial area
Akshardham Temple	Medium built-up area with green cover
Punit Van	Green cover
Vidhan Sabha	Medium built-up area with green cover
Kudasan	Medium built-up area
Indroda Park	Green cover
Gayatri Hospital	Densely built-up area
DAIICT	Built-up with green cover
Kisannagar Public Garden	Green cover
GIDC	Industrial estate

3. DATA USED

In the present study, Aqua-MODIS LST daytime and nighttime data (free available at NASA's Earth Data portal) (National Aeronautics and Space Administration) was retrieved for the city of Gandhinagar for a period of 18 years (2003-2020). This data is available at a spatial resolution of 1 km × 1 km and temporal resolution of 24 hours.

4. METHODOLOGY

The LST data retrieved for the available dates was annual averaged for the specific years and further averaged for the study area. Annually averaged LST mapping was done for the specific years (2003, 2009, 2011 and 2020) using ArcGIS 10.3.

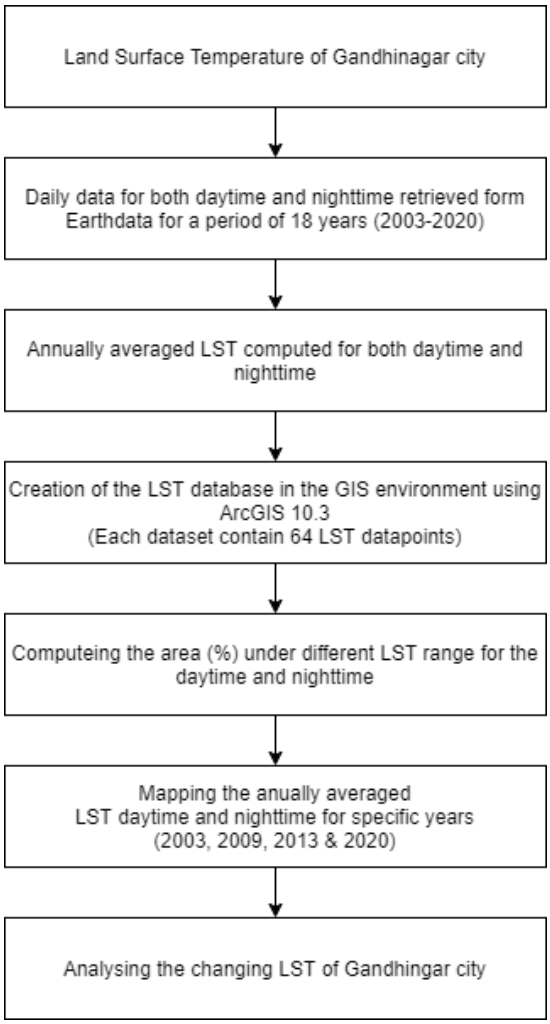

Fig. - 2: Methodology flowchart

5. RESULTS AND DISCUSSION

Trends in Daytime and Nighttime LST

Figures 3(a) and 3(b) illustrate the percentage area distribution of annually averaged LST for daytime and nighttime, respectively, accompanied by linear trend lines over the study period. These figures reveal contrasting trends: a **decreasing trend in daytime LST** and an **increasing trend in nighttime LST**. Such patterns align with findings from other global studies (Colacino & Rovelli, 1983; Karl et al., 1988; Mohan et al., 2011), underscoring the influence of urbanization on diurnal thermal dynamics.

The reduction in daytime LST can be attributed to urban surfaces absorbing heat during the day, which is subsequently re-radiated at night, contributing to elevated nighttime LST. This thermal behavior is exacerbated by a decline in green cover, which limits the cooling effect of vegetation and accelerates heat retention in impervious urban structures.

Changing Daytime LST

Figure 4 (a-b) illustrates the spatial distribution of annually averaged daytime LST over Gandhinagar for two selected years:

- **2003** (start of the study period), and
- **2020** (end of the study period).

During the study period, daytime LST values ranged from **40°C to 43°C**, showing a decreasing trend at a rate of **0.05°C/year**. A noticeable longitudinal thermal stratification developed over time, with distinct spatial patterns emerging by 2020.

- **Eastern regions**, dominated by green spaces such as **Indroda Park, Punit Van**, and the **Akshardham Temple**, consistently exhibited the **lowest daytime LST**, reflecting the cooling effect of vegetation.
- In contrast, the **western regions**, particularly the **GIDC industrial area**, recorded the **highest daytime LST**, highlighting the thermal impact of urban-industrial activity and impervious surfaces.

This spatial divergence underscores the role of land use and vegetation cover in influencing daytime thermal patterns in the city.

Changing Nighttime LST

Figure 5 (a-b) shows the spatial distribution of annually averaged nighttime LST for the same selected years (2003 and 2020). Over the study period, nighttime LST values ranged from **20°C to 22°C** and exhibited an increasing trend at a rate of **0.07°C/year**.

- In the **early years** of the study period, higher nighttime LST values were concentrated in the **central to northeastern regions** of the city.
- By the **later years**, the **central zone** emerged as the area with consistently higher nighttime temperatures, indicating a shift in thermal hotspots.
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The rising nighttime LST reflects the cumulative effect of heat retention by urban infrastructure, which re-radiates stored heat during the night. The urban core, with dense built-up areas and reduced vegetation, has become a prominent heat source during nighttime, further intensifying the urban heat island effect.

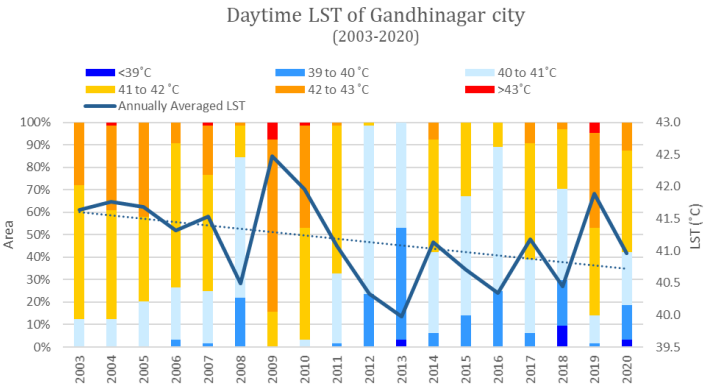

Fig -3(a): Area (%) of daytime LST over Gandhinagar city along with annually averaged LST during 2003- 2020

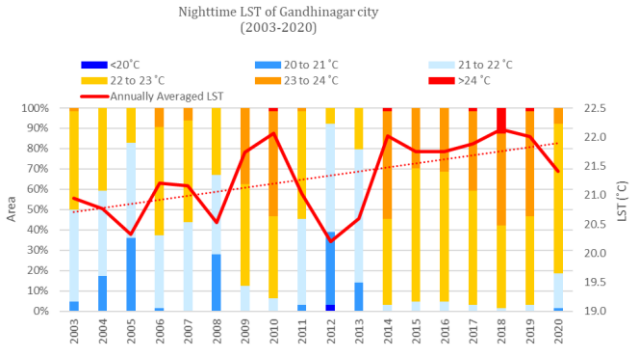

Fig -3(b): Area (%) of Nighttime LST over Gandhinagar city along with annually averaged LST during 2003 – 2020

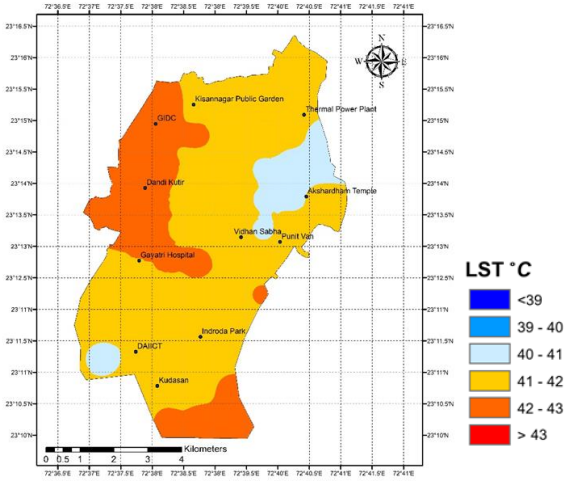

Fig -4 (a): Annually averaged daytime LST of Gandhinagar city for the year 2003

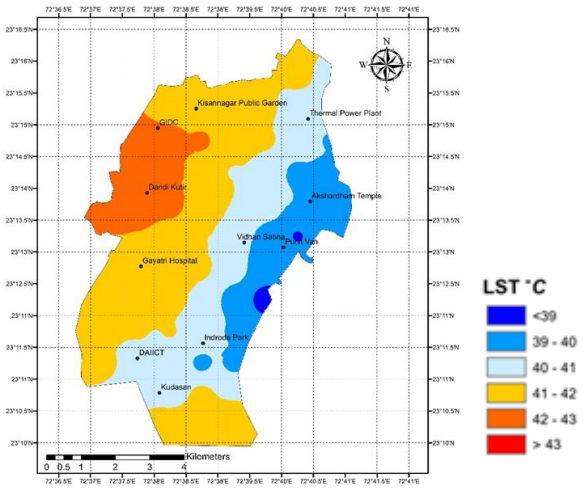

Fig -4 (b): Annually averaged daytime LST of Gandhinagar city for the year 2020

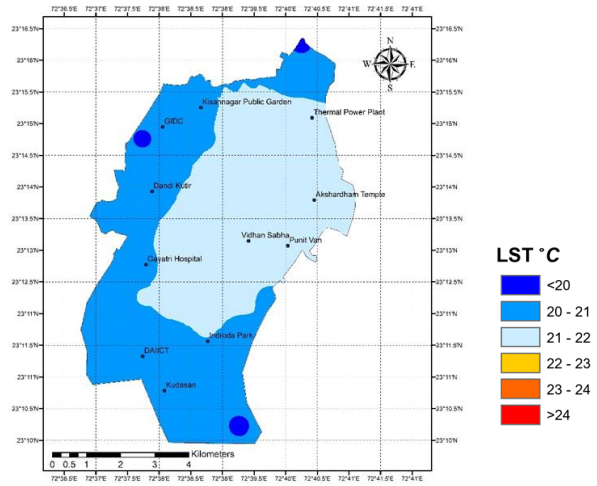

Fig -5 (a): Annually averaged nighttime LST of Gandhinagar city for the year 2003

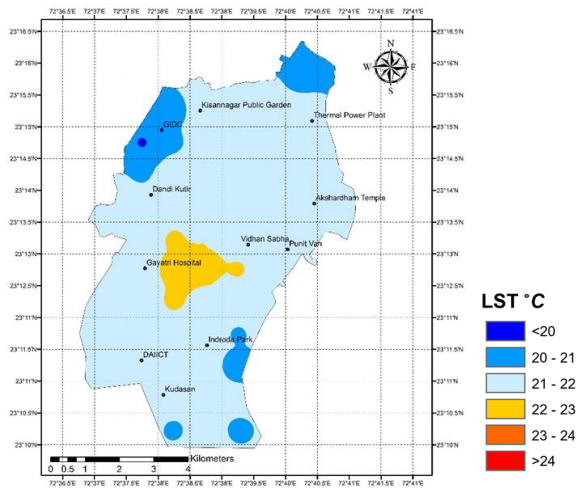

Fig -5 (b): Annually averaged nighttime LST of Gandhinagar city for the year 2020

6. CONCLUSIONS

The present study provides a comprehensive assessment of the temporal and spatial dynamics of Land Surface Temperature (LST) in Gandhinagar city, Gujarat, over an 18-year period (2003–2020), focusing on both daytime and nighttime LST variations. The findings reveal critical insights into the thermal behavior of the city and its evolution under the influence of urbanization, with several key conclusions outlined below:

6.1. Contrasting Trends in Daytime & Nighttime LST

A decrease in daytime LST and an increase in nighttime LST were observed, a pattern characteristic of urbanization. This reflects the absorption of solar radiation by impervious surfaces during the day and the subsequent re-radiation of stored heat at night, commonly associated with the urban heat island effect. The daytime LST declined at a rate of 0.05°C/year, while the nighttime LST rose at a rate of 0.07°C/year, indicating a more pronounced warming trend during the night compared to the cooling trend during the day.

6.2. Spatial Evolution of Thermal Patterns

Over the study period, the daytime LST exhibited a longitudinal thermal stratification, with distinct temperature variations across different regions of the city by 2020. Areas with significant green cover, such as Indroda Park, Punit Van, and the Akshardham Temple, consistently recorded the lowest daytime LST, underscoring the cooling effects of vegetation. Conversely, industrial zones, particularly in the GIDC area on the western side, emerged as daytime thermal hotspots due to the prevalence of impervious surfaces and urban activities. During the nighttime, the central zone of the city experienced a progressive increase in LST, highlighting the thermal inertia of densely built-up areas.

6.3. Urbanization & Its Thermal Impact

The trends observed align with broader global studies, reaffirming that urbanization significantly alters the thermal landscape of cities. The expansion of impervious surfaces, coupled with a decline in vegetative cover, intensifies heat retention and re-radiation processes, exacerbating nighttime warming. The findings highlight how the interplay between natural features and urban structures shapes the thermal environment. Green spaces effectively mitigate daytime heat, while densely urbanized areas with limited vegetation exhibit higher nighttime temperatures.

6.4. Implications for Urban Planning

The increasing nighttime LST and localized thermal hotspots raise concerns regarding the intensification of urban heat islands, with potential impacts on public health, energy consumption, and overall urban livability.

These findings underscore the need for climate-sensitive urban planning. Strategies such as expanding urban green spaces, increasing tree cover, using reflective building materials, and adopting sustainable urban designs can help mitigate LST changes and improve thermal comfort.

6.5. Broader Context & Future Directions

The study highlights the importance of continuous monitoring of LST to understand the long-term implications of urbanization on the thermal environment. Future studies could expand on this work by incorporating additional variables such as population density, land use changes, and socio-economic factors to provide a more holistic understanding of urban thermal dynamics. The integration of advanced modeling approaches and higher-resolution satellite data can enhance the accuracy of LST predictions and inform more targeted urban interventions.

In conclusion, the study establishes that urbanization in Gandhinagar has led to discernible changes in its thermal environment, with decreasing daytime temperatures and increasing nighttime temperatures. The spatial patterns emphasize the critical role of green infrastructure in moderating urban heat. Addressing these thermal challenges through informed urban planning and adaptive strategies will be crucial for ensuring the sustainability and resilience of Gandhinagar as it continues to develop.

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