iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 Issue: VIII Month of publication: August 2026

DOI: https://doi.org/10.22214/ijraset.2026.84522

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Assessing Urban Heat Dynamics Using Satellite-Derived Land Surface Temperature: A Case Study of Chennai, India

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Abstract: Coastal cities are increasingly facing thermal stress due to rapid urban growth, land-use change, and climate variability. Chennai, a major coastal city in southern India, exemplifies this challenge, where extensive urban development coexists with ecologically sensitive peri-wetlands and a dynamic land–sea boundary. This study examines the spatial and temporal variation of land surface temperature (LST) across distinct land-use categories in Chennai using satellite-derived data. LST was obtained from the MODIS MOD11A2 Version 6.1 product (8-day composite, 1 km spatial resolution) through the AppEEARS platform for four representative locations — urban, coastal, peri-wetland, and industrial — over an 11-year period (2015–2025). Coastal observations were affected by persistent mixed land–water pixel contamination (0% valid retrievals) and were therefore excluded from the quantitative analysis; this limitation and possible mitigation strategies are discussed explicitly. Statistical, diurnal, and seasonal analyses of the remaining three classes reveal a consistent Surface Urban Heat Island (SUHI) effect, with urban areas exhibiting the highest daytime and night-time temperatures and the lowest diurnal temperature range (DTR). Relative to earlier Chennai UHI studies, this work extends the observational record to 2025, explicitly incorporates a peri-wetland comparison class, and combines diurnal and seasonal decomposition within a single reproducible, low-code AppEEARS-based workflow. The findings can inform sustainable urban planning, climate adaptation, and ecosystem conservation in coastal urban settings.
Keywords: Land Surface Temperature (LST); Urban Heat Island (UHI); Surface Urban Heat Island (SUHI); MODIS; Remote Sensing; Chennai; Coastal Urbanization

I. INTRODUCTION

The elevation of surface temperatures in urban areas — commonly referred to as the urban heat island (UHI) effect — has emerged as a major concern for environmental sustainability and human well-being. Urban heat islands are expressed as elevated temperatures in built-up areas compared to surrounding rural or natural landscapes. This phenomenon is driven by the replacement of natural land cover with impervious materials, reduced vegetation, and increased anthropogenic heat emissions. Understanding land surface temperature (LST) variation is vital for assessing urban climate patterns and informing sustainable urban planning.

LST, derived from thermal infrared satellite observations, provides an indicator of surface thermal state and has been widely used to analyze UHI effects. MODIS products are commonly used for LST research owing to their temporal resolution and global coverage. Tools such as AppEEARS have simplified access to these datasets by enabling users to extract time-series data without advanced programming skills. Chennai's proximity to the Bay of Bengal brings climatic influences including sea-breeze circulation, coastal humidity, and monsoonal patterns, which interact with urban morphology to shape surface temperature distribution.

This paper investigates the spatial and temporal variability of LST across representative land-use categories in Chennai — urban, peri-wetland, and industrial — using a point-based sampling approach applied to an 11-year MODIS LST record (2015–2025). This allows identification of long-term trends as well as seasonal and diurnal variation.

While Chennai's UHI has been studied previously (Section II), this work differs from prior studies in three respects. First, it extends the observational record through 2025, several years beyond the datasets used in earlier Chennai UHI studies. Second, it explicitly incorporates a peri-wetland class as a natural-cover comparison alongside urban and industrial zones, a distinction less commonly isolated in existing literature. Third, it combines statistical, diurnal (day/night), and seasonal decomposition within a single reproducible workflow built entirely on the openly accessible AppEEARS platform, making the approach easy to replicate for other coastal cities with similar data constraints.

II. LITERATURE REVIEW

Initial investigations into UHI intensity in Chennai pointed to the impact of rapid urban growth, decreased vegetation, and expanded built-up areas on surface temperature trends [1]. Later research confirmed these observations, showing distinct spatial differences throughout the metropolitan area. Jeganathan et al. found notable spatial variation in LST, with densely populated urban centers exhibiting higher temperatures than outlying and coastal regions [2].

Kesavan et al. used ARIMA-based modelling to forecast LST trends and quantify UHI intensity, revealing a steady warming trend linked to urban growth [3]. Similarly, Muthiah et al. associated peri-urban expansion with rising thermal anomalies, emphasizing the vulnerability of transitional landscapes [4]. More recent studies, such as those by Grace et al. and Sethuraman et al., examined decadal change, underscoring the combined effects of industrialization and infrastructure development on urban thermal patterns [5], [6]. Together, these studies indicate that UHI in coastal cities is shaped not only by urban density but also by proximity to coastlines, land–sea interaction, and local environmental factors.

MuraliKrishna and Sahithi demonstrated a significant correlation between land use/land cover (LULC) change and LST fluctuation in Chennai, showing that urban expansion markedly raises surface temperature [7]. Rastogi and Sharma found that LST anomalies can effectively indicate urban density and surface urban heat island intensity [8]. Ranjan et al. showed that urban growth affects both LST and aerosol levels, highlighting the interconnectedness of urban environmental systems [9]. Badugu et al. applied data-driven approaches to model LST change, confirming the effectiveness of statistical and machine-learning techniques for studying urban heat [10].

In the Indian context specifically, Grace et al. examined UHI dynamics in a coastal industrial setting, highlighting the combined effect of industrialization and coastal proximity on thermal patterns [5]. Panda and Rath studied how sea-surface temperature and land-use change contribute to extreme weather events in Chennai [11], and, in related work, examined near-surface boundary-layer characteristics during the 2015 Chennai flood in the context of urban-induced land-use change [13]. Mathew et al. studied the relationship between UHI and air pollution, finding significant correlations between thermal anomalies and environmental degradation [12].

Collectively, these studies establish that Chennai exhibits a measurable and persistent UHI/SUHI signal. However, most focus on urban-versus-rural contrasts over shorter or older observation windows, and few isolate a peri-wetland class or explicitly discuss the practical limitations of coastal-pixel sampling in moderate-resolution thermal products — the gaps this study addresses.

III. METHODOLOGY

A. *Study Area and Sampling Design*

Chennai was selected as the study area, with four coordinate points representing Urban (T. Nagar, central Chennai), Coastal (Marina Beach), Peri-Wetland, and Industrial (Ennore Industrial Area) land-use classes (Table I, Fig. 1). Each point was submitted as a single-pixel AppEEARS point-sample request against the MOD11A2 Version 6.1 product (Table II).

TABLE I
LAND-USE CLASS SAMPLING LOCATIONS

Land-Use Class	Latitude	Longitude	Data Status
Urban	13.0418	80.2341	Valid (75.5%)
Industrial	13.2143	80.3203	Valid (78.1%)
Peri-Wetland	12.9488	80.2086	Valid (69.2%)
Coastal	13.0500	80.2824	Invalid (0%)

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
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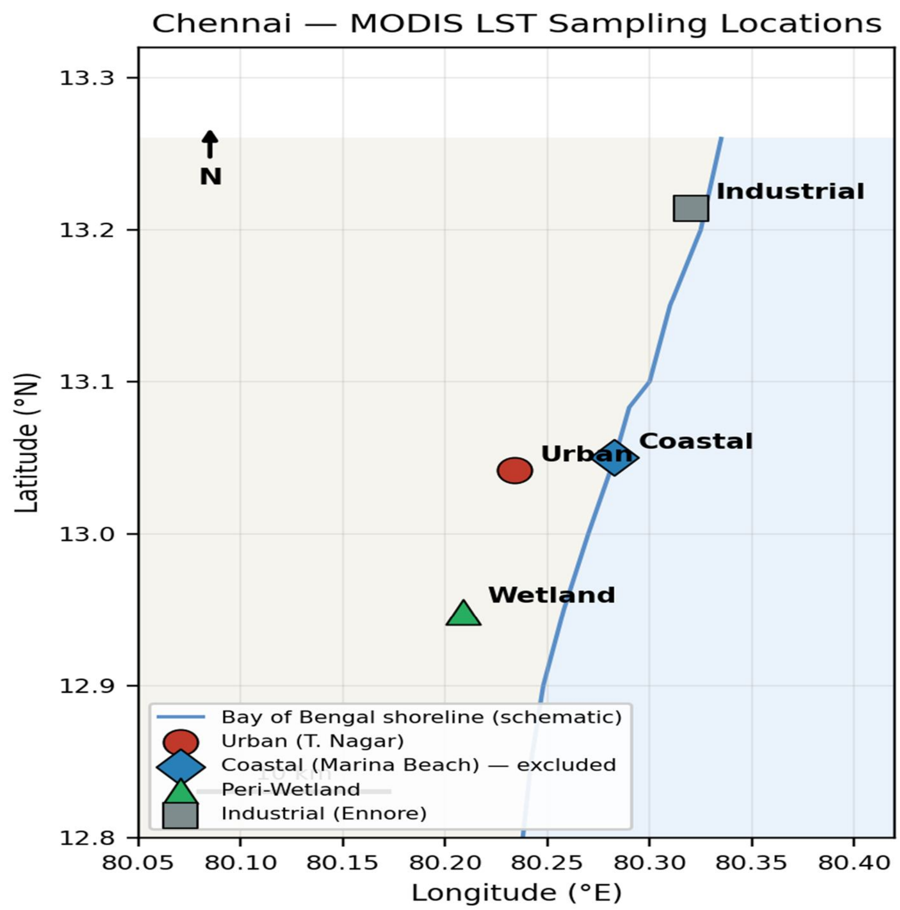

Fig. 1 Locations of the four AppEEARS sampling points overlaid on a schematic map of Chennai and the Bay of Bengal shoreline (coastline shown for orientation only, not to survey accuracy).

B. Data Source and Quality Control

LST data were obtained from the MOD11A2 Version 6.1 product (8-day composite, 1 km spatial resolution) for Day and Night bands, spanning 1 January 2015 to 31 December 2025 (Table II), yielding 506 composite records per land-use class (2,024 records in total). Per-pixel retrieval quality was assessed using the MODIS QC bitmask, comprising the MODLAND QA flag, the data-quality flag, the average emissivity-error flag, and the average LST-error flag. Records flagged as "LST not produced" (MODLAND QA = 11, i.e., LST_Day/Night = 0 K) were treated as missing and excluded prior to statistical analysis.

Applying this criterion retained 78.1% of records for the Industrial class (395 of 506), 75.5% for Urban (382 of 506), and 69.2% for Peri-Wetland (350 of 506). The Coastal point returned 0% valid retrievals across the full 11-year record — every composite was flagged as unproduced, consistent with persistent mixed land–water pixel contamination at 1 km resolution near the Marina Beach shoreline. Because no valid thermal signal could be recovered at any point in the series, the Coastal class was excluded from the quantitative analysis rather than imputed.

TABLE II
APPEEARS REQUEST PARAMETERS

Parameter	Value
Request Name	Chennai_points
Start / End Date	01-01-2015 to 31-12-2025
Layers	LST_Day_1km, LST_Night_1km (MOD11A2.061)

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C. Coastal Data Limitation and Alternative Strategies

Complete signal loss at the Coastal point is a recognized issue in moderate-resolution thermal datasets near land–sea boundaries, where a single 1 km pixel can span both water and land surfaces with markedly different emissivity, causing the retrieval algorithm to reject the composite. Three mitigation strategies were considered but not implemented in this iteration, and are noted here as directions for follow-up work rather than as limitations that were silently absorbed: (i) relocating the sampling point further inland to a coastal-influenced but fully terrestrial pixel; (ii) substituting a higher-resolution thermal product (e.g., Landsat-derived LST at 30–100 m) for the coastal class only; and (iii) applying sub-pixel or mixed-pixel unmixing techniques to recover a land-only thermal signal from the existing MODIS composite. Given the scope and timeline of this study, the Coastal class was instead excluded and is flagged as an explicit limitation (Section V).

D. Statistical and Temporal Analysis

For each of the three valid classes, descriptive statistics (mean, standard deviation, minimum, maximum) were computed separately for Day and Night LST (Table III). Diurnal temperature range (DTR) was calculated per composite as the Day–Night LST difference and summarized by class (Table IV). Monthly climatology was derived by averaging all valid observations within each calendar month across the 11-year record, producing a seasonal profile with associated inter-annual standard deviation (Fig. 3–5). Fig. 2 summarizes the complete workflow from data acquisition through synthesis.

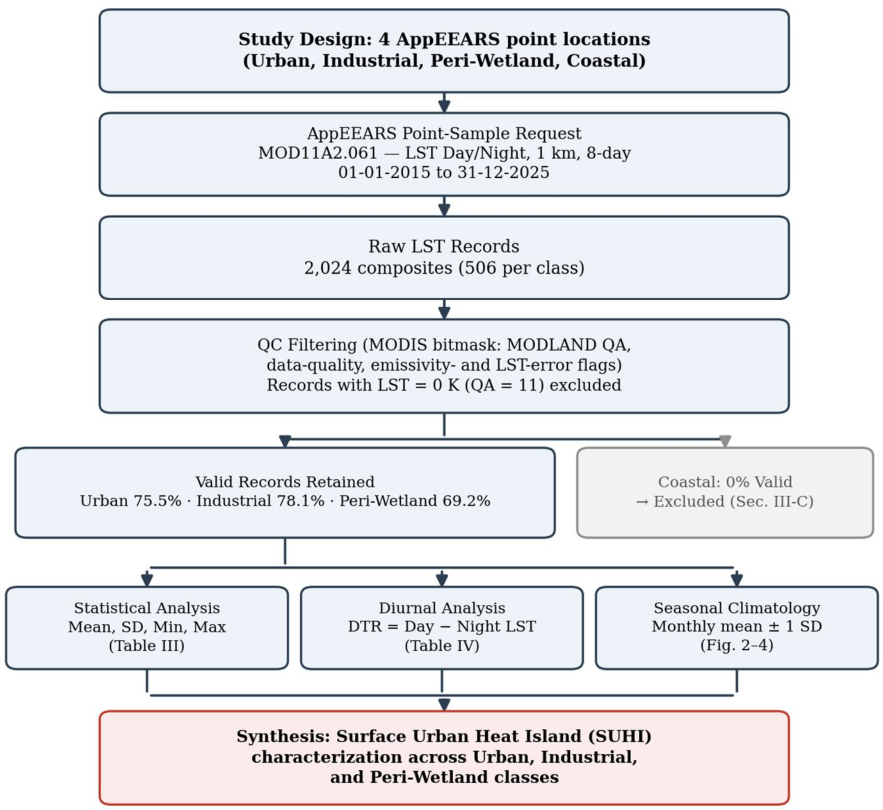

Fig. 2 Overall study workflow, from AppEEARS data acquisition and QC filtering through statistical, diurnal, and seasonal analysis to SUHI synthesis.

IV. RESULTS AND DISCUSSION

The analysis is based on the 11-year (2015–2025) MODIS LST record described in Section III, restricted to the three classes with valid retrievals: Urban, Industrial, and Peri-Wetland. The dataset includes both Day and Night LST, allowing evaluation of thermal intensity, diurnal variation, and seasonal trends across land-use types.

A. Statistical Thermal Profile

Urban areas show the highest mean daytime LST at 34.57 °C (±3.47), followed by Peri-Wetland at 33.81 °C (±3.41) and Industrial at 32.72 °C (±2.93); the maximum recorded daytime LST in the Urban class is 43.61 °C (Table III). On average, Urban areas are 1.85 °C warmer than Industrial and 0.76 °C warmer than Peri-Wetland during the day, consistent with heat retention by impervious surfaces, reduced vegetation cover, and anthropogenic heat emission. At night, the Urban class remains warmest, averaging 26.58 °C (±1.87) compared with 25.82 °C (±1.64) for Industrial and 25.45 °C (±1.85) for Peri-Wetland — a smaller gap than during the day, but one that persists consistently across the record, indicating gradual release of stored daytime heat from built surfaces.

TABLE III
THERMAL SUMMARY BY LAND-USE CLASS (VALID CLASSES ONLY)

Class	Day Avg. (°C)	Day Max. (°C)	Night Avg. (°C)	Night Min. (°C)
Urban	34.57 (±3.47)	43.61	26.58 (±1.87)	21.75
Peri-Wetland	33.81 (±3.41)	42.71	25.45 (±1.85)	20.95
Industrial	32.72 (±2.93)	40.99	25.82 (±1.64)	19.61

B. Diurnal Temperature Range (DTR)

DTR provides additional insight into surface thermal behaviour beyond mean temperature alone (Table IV). Peri-Wetland shows the highest DTR at 8.36 °C, indicating efficient daytime heating and rapid night-time cooling driven by moisture availability and evapotranspiration. Urban areas show a lower DTR of 7.98 °C, reflecting slower heat release from built materials, while Industrial areas show the lowest DTR at 6.90 °C, suggesting a comparatively stable but persistently warm thermal regime tied to structural density and continuous operational heat emission. This ordering — natural cover exhibiting the greatest diurnal swing and built environments suppressing it — is consistent with the physical mechanism of thermal inertia in impervious materials.

TABLE IV
DIURNAL TEMPERATURE RANGE (DTR) BY LAND-USE CLASS

Class	Mean DTR (°C)	Std. Dev. (°C)
Peri-Wetland	8.36	2.46
Urban	7.98	2.63
Industrial	6.90	2.18

C. Seasonal Climatology

Monthly climatology (Fig. 3–5) shows a sharp temperature rise beginning in March and peaking in May–June for all three classes. Urban and Peri-Wetland reach a similar peak daytime magnitude, but the Urban class maintains a higher night-time "floor" temperature throughout the year, consistent with its role as a thermal reservoir. Between May and August, Peri-Wetland shows a steeper temperature decline than Urban, a qualitative signature of moisture-driven cooling that is comparatively suppressed on sealed urban surfaces. Peak daytime LST reaches approximately 38.0 °C in Urban areas, 37.6 °C in Peri-Wetland, and 35.2 °C in Industrial areas during May–June, while winter (December–January) values fall to approximately 24–30 °C across all three classes. The Urban–Peri-Wetland–Industrial thermal hierarchy remains consistent throughout the 11-year record and across seasons, and the gap between Urban and non-urban classes widens specifically during summer, indicating that seasonal climatic conditions amplify rather than mask the SUHI signal.

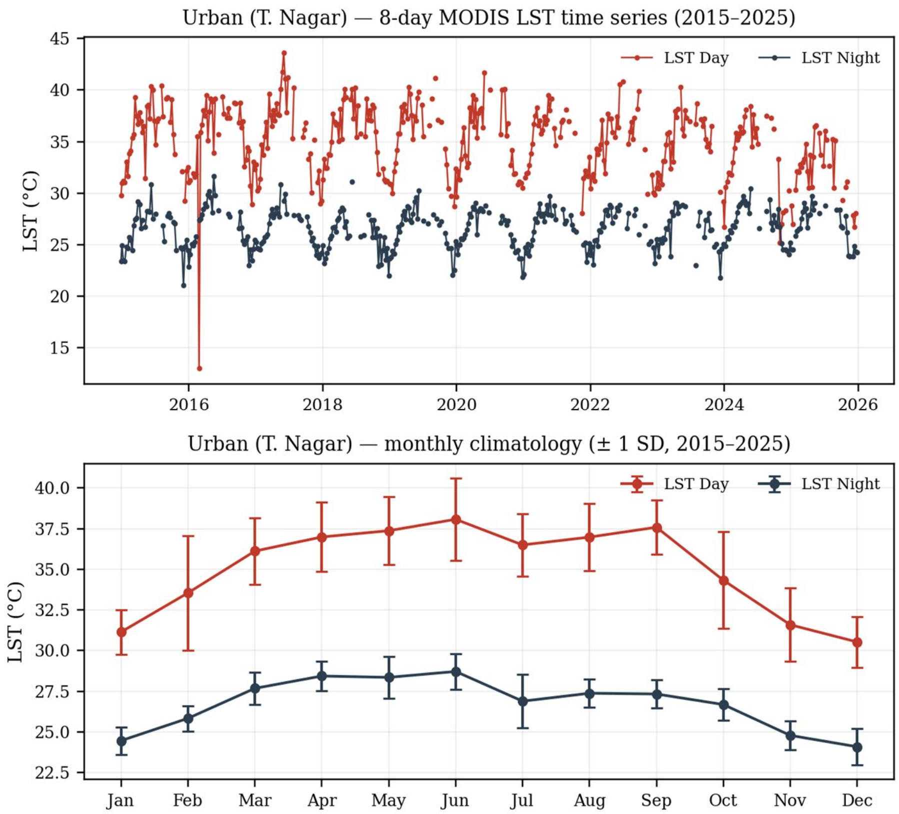

Fig. 3 Time series (top) and monthly climatology (bottom, ±1 SD) of Day/Night LST for the Urban class, 2015–2025.

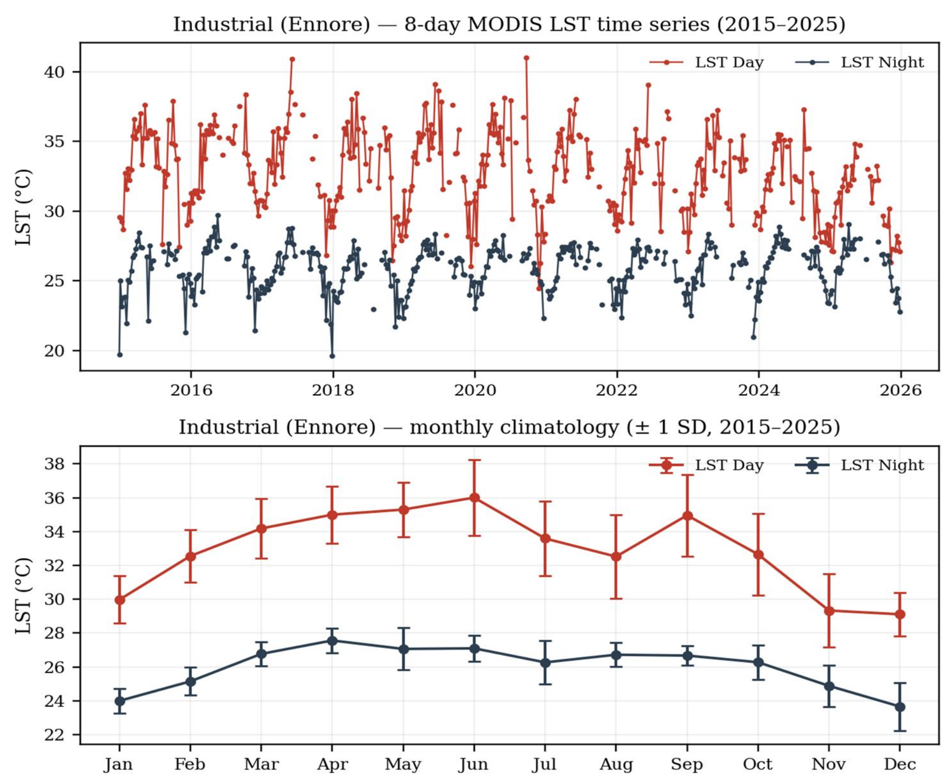

Fig. 4 Time series (top) and monthly climatology (bottom, ±1 SD) of Day/Night LST for the Industrial class, 2015–2025.

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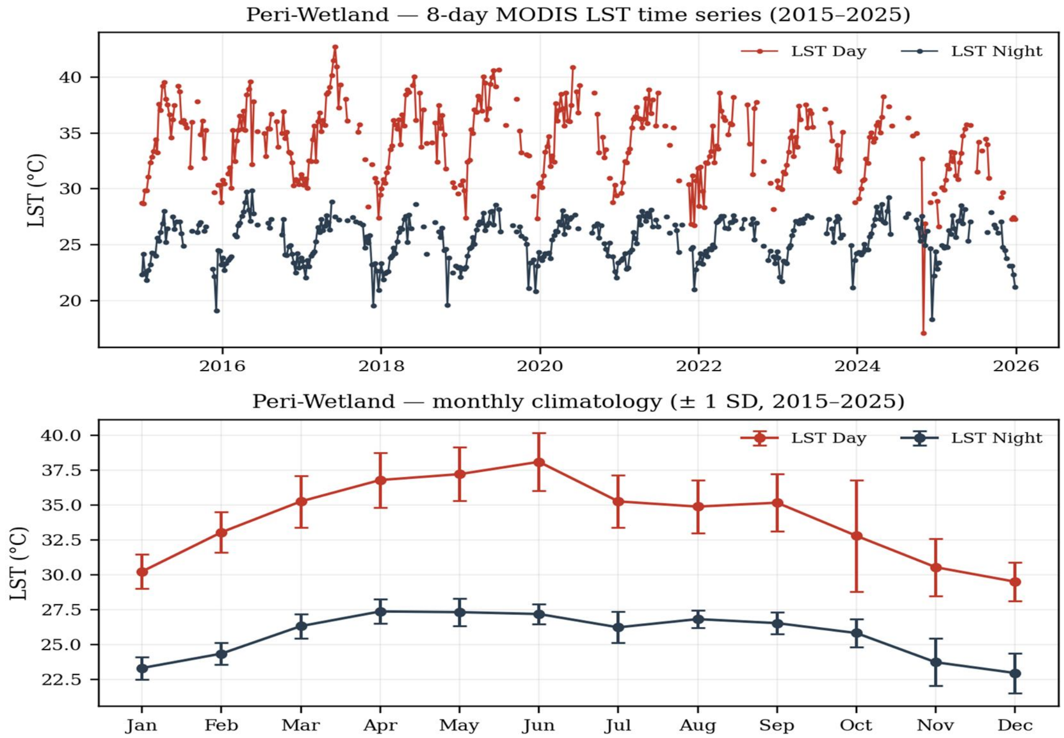

Fig. 5 Time series (top) and monthly climatology (bottom, ±1 SD) of Day/Night LST for the Peri-Wetland class, 2015–2025.

D. Synthesis

Across statistical, diurnal, and seasonal analyses, Urban areas consistently show the highest mean and peak temperatures, the lowest diurnal variability, and persistent night-time heat retention — the combined signature of a Surface Urban Heat Island. Peri-Wetland areas, by contrast, show lower mean temperatures, higher diurnal variability, and a stronger night-time cooling response, supporting their role as a natural thermal buffer within the urban–coastal landscape.

V. LIMITATIONS

This study has three limitations that should guide interpretation of the results and future work. First, each land-use class is represented by a single 1 km pixel; while consistent with a low-cost, reproducible AppEEARS-based workflow, single-pixel sampling cannot capture intra-class heterogeneity, and results should be read as indicative of each site rather than the class as a whole across Chennai. Second, the Coastal class could not be analysed quantitatively due to complete retrieval failure (0% valid records) at 1 km resolution near the land–sea boundary; Section III-C outlines relocation, higher-resolution substitution, and sub-pixel unmixing as directions for recovering a coastal thermal signal in follow-up work. Third, this study relies on satellite-derived LST alone, without validation against ground-based meteorological observations or an independent LST product; such validation would strengthen confidence in the absolute temperature values reported here, even though the relative Urban–Peri-Wetland–Industrial ordering is consistent with the established physical mechanisms of surface urban heat islands.

VI. CONCLUSION

This study evaluated land surface temperature (LST) dynamics across three land-use categories in Chennai using an 11-year (2015–2025) MODIS MOD11A2 dataset accessed via AppEEARS. Statistical, diurnal, and seasonal analyses consistently demonstrate a Surface Urban Heat Island (SUHI) effect: Urban areas show the highest daytime (34.57 °C) and night-time (26.58 °C) mean LST and the lowest diurnal temperature range (7.98 °C), while Peri-Wetland areas act as a comparative cooling zone with the highest diurnal range (8.36 °C). The SUHI signal intensifies during the pre-monsoon summer (May–June) and narrows, but does not disappear, during the winter months. A fourth, Coastal, class could not be analyzed due to complete retrieval failure at 1 km resolution near the shoreline — a limitation discussed explicitly along with three concrete mitigation strategies for future work.

Relative to earlier Chennai UHI studies, this work contributes a longer and more current observational record, an explicit peri-wetland comparison class, and a combined diurnal–seasonal analytical framework built on a fully reproducible, low-code workflow. The results support the case for conserving peri-wetland areas as natural cooling zones, targeting heat-mitigation measures at persistently warm urban and industrial pockets, and accounting for night-time heat retention — not only daytime peaks — in coastal urban planning and climate-adaptation policy.

VII. ACKNOWLEDGMENT

The author acknowledge the NASA Land Processes Distributed Active Archive Centre (LP DAAC) for providing MODIS LST data and the AppEEARS platform used for data extraction in this study.

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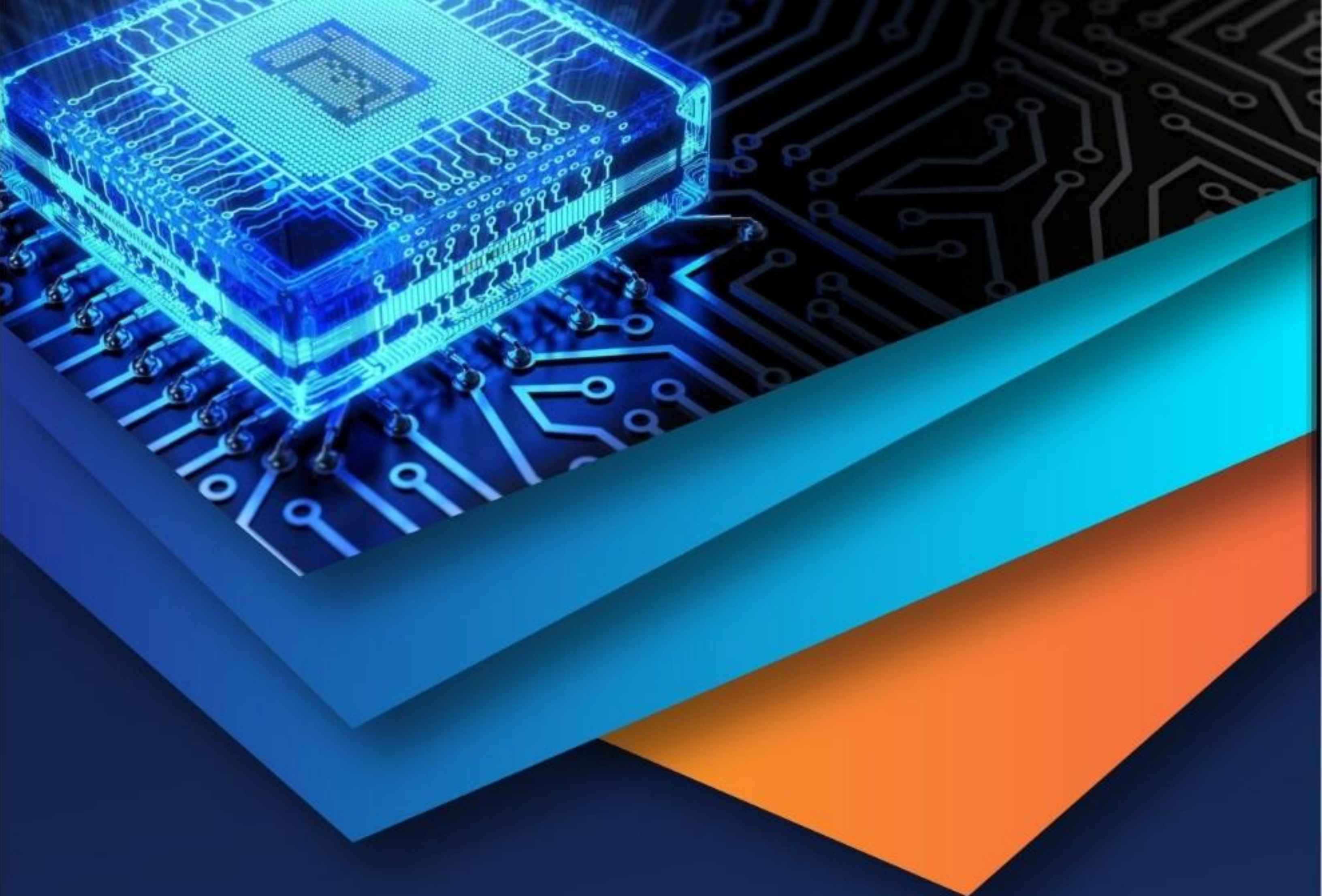

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