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Interplay Between Rooftop Solar Photovoltaics and the Urban Thermal Environment: A Case Study of Lucknow, India

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Abstract: Rapid urbanization in Indian cities has intensified Urban Heat Island (UHI) effects, increased surface temperatures and placing additional stress on urban energy systems. While rooftop solar photovoltaic (PV) installations are primarily deployed for renewable energy generation, they also influence urban thermal behavior by modifying radiative exchange processes, surface albedo, and roof shading. Focusing on Lucknow, a rapidly expanding city in northern India, this study investigates the interplay between rooftop solar deployment and the urban thermal environment within dense built-up areas using satellite-derived Land Surface Temperature (LST) data.

Multi-temporal Landsat imagery for 2019 and 2023 was processed in a GIS framework to analyze spatial patterns of LST, ΔLST, and the distribution of urban heat and cool zones. Results indicate a reduction in peak surface temperature from 39.7 °C in 2019 to 34.6 °C in 2023, with pronounced cooling observed in environmentally buffered zones such as the Gomti River corridor, Kukrail Reserve, and Cantonment area. During the same period, solar-covered rooftop area expanded by approximately 131%, increasing from 170,472.20 m² to 393,974.23 m². Spatial correlation analysis shows that wards with higher rooftop solar density tend to exhibit comparatively lower LST values, suggesting localized thermal moderation associated with PV installations through shading and reduced heat absorption.

In addition to thermal implications, the growth in solar generation from 58.24 GWh to 132.75 GWh annually corresponds to an estimated avoidance of about 93,487 $tCO_2\ yr^{-1}$, equivalent to roughly 93,000 carbon credits under India's Carbon Credit Trading Scheme. The findings highlight rooftop solar photovoltaics as a dual-benefit strategy contributing to both urban heat mitigation and low-carbon energy transition. This study provides empirical evidence for integrating distributed solar infrastructure into climate-sensitive urban planning, offering actionable insights for developing thermally resilient and sustainable cities in rapidly urbanizing regions.

Keywords: Urban Heat Island (UHI); Land Surface Temperature (LST); Rooftop Solar Photovoltaics; Urban Thermal Environment; Dense Built-Up Areas; Remote Sensing; Carbon Offset

I. INTRODUCTION

As the world shifts toward low-carbon and sustainable energy systems, solar photovoltaic (PV) technology is recognized as an important part of renewable energy development (International Energy Agency, 2023). Solar PV is now an essential strategy to achieve carbon-neutral goals and accelerating the global transition to sustainable energy as worries about urban air pollution, energy security, and global warming grow along with the global demand for energy(Intergovernmental Panel on Climate Change (IPCC), 2022) (International Energy Agency, 2023). The challenge of urban heat islands (UHI) has intensified due to the fundamental changes in land cover and surface heat dynamics created by the expansion of cities. With accelerating sprawl in developing countries, UHI assessment has become a critical tool for urban planners and environmental managers to monitor, model, and manage urban growth (Rashid, 2022) Since the 1990s, technological advancements, supportive government policies, and heightened climate awareness have driven large-scale PV deployment worldwide (Renewable Energy Policy Network for the 21st Century, 2023).

Remote sensing techniques, particularly LST retrieval from satellite imagery, are essential for quantifying spatial and temporal UHI dynamics and identifying localized hotspots (Voogt & Oke, 2003);(U.S. Environmental Protection Agency, 2008). On the other hand, by lowering the surrounding temperature and improving environmental comfort, cool spots such as vegetated parks, bodies of water, or solar-powered rooftops with reflective materials play a critical role in balancing the thermal load of urban heat corridors.

Energy use, urban environmental quality, and human thermal comfort are all adversely affected by elevated LST. Recent studies indicate that rooftop solar panels can modify surface albedo and thermal properties, thereby mitigating local temperature patterns and potentially alleviating surface heat stress (A. Khan et al., 2024). There is a spatial imbalance in urban thermal comfort caused by the luxury effect, which is the tendency for affluent urban areas to have cooler microclimates because of increased vegetation cover, sophisticated infrastructure, and adaptive technologies(G. Darrel Jenerette n.d.; Zhang 2021). By offering both localized cooling benefits and access to clean energy, integrating rooftop solar solutions across socioeconomic strata can help close this gap, advancing environmental equity while encouraging sustainable urban development (Chow, 2012; Santamouris, 2014).

Few studies have analyzed the spatial-temporal effect of rooftop solar panels on LST or evaluated linked environmental advantages, such as potential carbon credits, despite their extensive deployment as part of worldwide renewable energy projects (Huang, 2021; International Energy Agency, 2023; Renewable Energy Policy Network for the 21st Century, 2023). According to the International Renewable Energy Agency (Renewable Energy Agency, 2022), worldwide PV systems avoided approximately 1.2 gigatonnes of CO_2 emissions in 2021 alone. This important reduction indicates PV's role in mitigating greenhouse gas (GHG) emissions, improving urban air quality, and contributing to national promises under the Paris Agreement (Intergovernmental Panel on Climate Change (IPCC), 2021). Integrating solar deployment with high-resolution building footprint data and LST analysis remains an under investigated area of research, particularly in mid-sized Indian cities experiencing rapid urban expansion (U. Gupta, 2025).

An ideal case study for examining the relationships between urbanization, rooftop solar PV use, and modifications to thermal energy is Lucknow, the capital of Uttar Pradesh, India (Sharma, n.d.; P. , & G. A. Singh, 2021). City's ongoing built-up expansion and new road development continue to degrade the environment, evident through worsening air quality, loss of vegetation, and rising heat exposure underscoring the urgent need for environmentally practical solutions (CPCB, 2023; R. and P. A. Gupta, 2020; Sharma, n.d.). Significant heat corridors are emerging along the commercial and transportation zones in Lucknow, which contrast with solitary coolspots formed by open water, solar rooftop photovoltaic clusters, and vegetated regions (Rashid, 2022) .The increasing usage of solar energy offers an efficient means to address climate change while building a healthier lifestyle for future generations by reducing carbon emissions. The global push for decarbonization and commitments to the Paris Agreement have further positioned solar PV as a cornerstone technology for mitigating greenhouse gas (GHG) emission (Intergovernmental Panel on Climate Change (IPCC), 2021; Renewable Energy Agency, 2022). Rooftop solar energy integration is consistent with both climate adaptation and mitigation strategies in India, as cities like Lucknow are rapidly becoming more populated. By lowering dependence on traditional grids and establishing decentralized, low-carbon energy clusters throughout quickly expanding areas, its broad use further enhances urban energy resilience. PV systems immediately reduce carbon emissions by replacing fossil fuel-based grid electricity, which is a key component of India's Nationally Determined Contributions (NDCs) and renewable energy ambitions (Government of India, 2022; International Energy Agency, n.d.; Ministry of New and Renewable Energy, 2023)

The saved CO_2 emissions that each unit of solar-generated electricity represents under carbon trading and environmentally friendly frameworks reflect the possibility for carbon credits that could encourage the use of solar power in metropolitan areas (Central Electricity Authority, 2023; United Nations Framework Convention on Climate Change, 2023). Rooftop solar hence functions as a technology that both cools the climate and earns carbon credits. The present research explores how Lucknow's increasing number of rooftop solar systems affects urban thermal behaviour and increases the opportunity for carbon offsets. According to the study, solar-integrated zones are new microclimate stabilizers that enhance sustainability and further the city's low-carbon growth trend.

This study aims to investigate the temporal and spatial dynamics between changes in surface temperature in Lucknow and rooftop solar uptake using geospatial and remote sensing techniques. The specific objectives are to: (i) Map and assess the spatiotemporal expansion and distribution of rooftop solar installations throughout the study area, 2019-2023 in order to determine their contribution to sustainable urban development and the integration of renewable energy; (ii) Examine the temporal and spatial patterns of LST for 2019 and 2023 to identify ongoing and emerging hotspot and cool spot zones, thereby illustrating the evolution of surface thermal behaviour over Lucknow's city. (iii) Measure the cooling impact of solar-enabled rooftops by comparing LST variations across solar and non-solar building clusters and evaluating thermal improvements based on ΔLST in solar-dense areas. (iv) Calculate the potential carbon offset and related environmental co-benefits derived from rooftop solar adoption, emphasising its contribution towards low-carbon urban transitions and climate resilience.

To achieve these objectives, the study employs multi-source geospatial datasets including rooftop solar photovoltaic inventory, building footprint data from GEE of year 2019 and 2023, and Landsat-derived LST for the years 2019 and 2023 processed through remote sensing and GIS-based analytical workflows.

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By integrating thermal irregularity detection, spatial overlay, and change detection analyses, this research positions rooftop solar systems not only as renewable energy infrastructures but also as transformative urban cooling interventions contributing to sustainable, carbon-neutral city development.

II. MATERIALS AND METHODS

A. Study Area

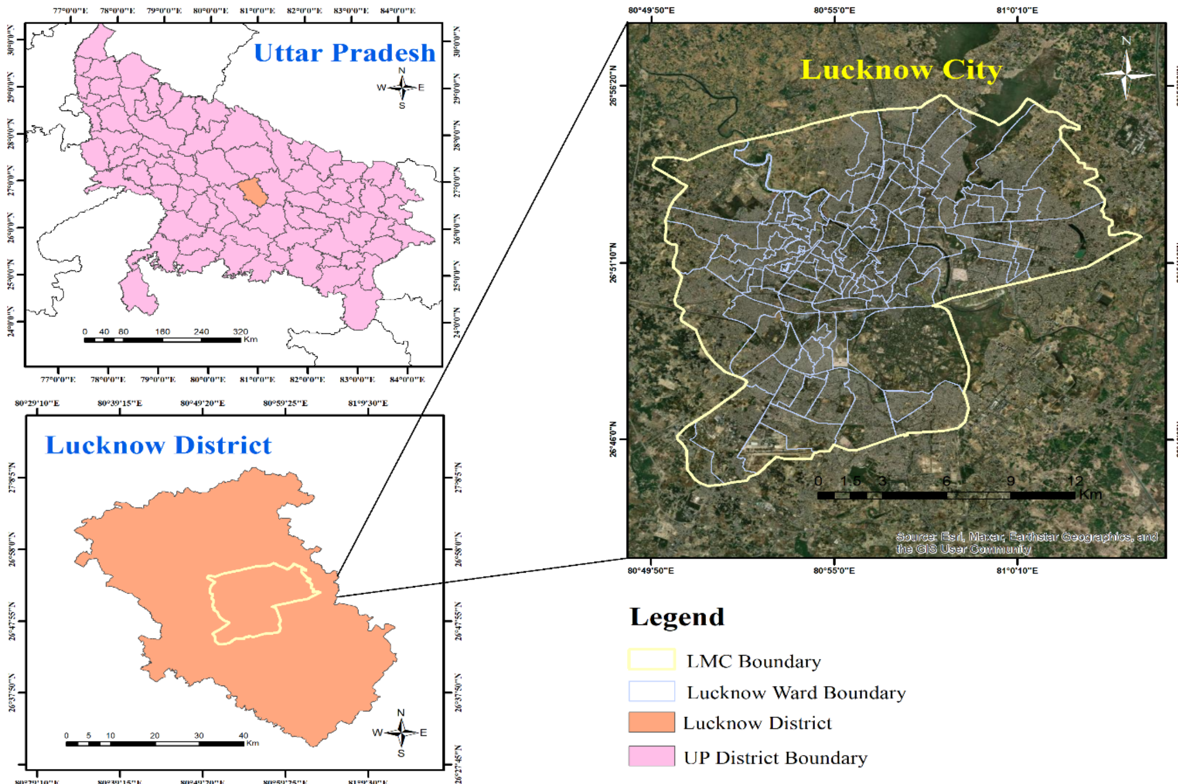

Figure 1: Study Area Map of Lucknow Municipal Corporation, Uttar Pradesh, India

Lucknow, the capital city of Uttar Pradesh, is situated on either side of the Gomti River at approximately 26°51′00″ N latitude and 80°55′00″ E longitude, with an average elevation of about 123 meters above mean sea level in the Central Gangetic Plain of northern India. The jurisdiction of the Lucknow Municipal Corporation (LMC) extends between 26°44′39″ N to 26°56′05″ N latitudes and 80°49′52″ E to 81°03′40″ E longitudes, covering an administrative area of approximately 283.45 km² (Lucknow Municipal Corporation, 2023; Office of the Registrar General and Census Commissioner, n.d.).

Geographically, Lucknow have rich soils and flat alluvial structure that have historically supported rapid construction of infrastructure and dense population growth (Dutta, 2012). Because of its humid subtropical climate, Lucknow experiences extremely hot summers (reaching up to 42°C), relatively cold winters (dropping to nearly 8°C), and a pronounced monsoon season from June to August. These seasonal variations strongly influence the city's surface energy balance, making Lucknow an appropriate setting for analysing LST and Urban Heat Island (UHI) dynamics (India Meteorological Department 2023; Sarif and Gupta 2019).

Lucknow's built-up area increased from 53.86 km² in 1991 to 261.45 km² in 2021, reflecting the city's substantial urban expansion over the last few decades (S. and A. R. and P. P. Khan, 2024; Kikon, 2016) and the Lucknow Development Authority (LDA, 2023) established a planning framework that forms the administrative boundaries of Lucknow city, which involves seven zones and 112 wards: Figure 1. The core built-up zone, which consists of Hazratganj, Charbagh, Aminabad, and Gomti Nagar, is substantially urbanized, while peripheral regions such as Jankipuram, Chinhat, and Indira Nagar are undergoing significant land-use conversion and urban expansion (Lucknow Development Authority, 2023; P. and K. P. Singh, 2021)

Urban heat islands and higher LST are results of these spatial alterations that have significantly altered the city's surface thermal environment (Sarif & Gupta, 2019; Uma Singh & Sarika Shukla, 2023). Between 1991 and 2021, there was a notable loss of flora, mostly as a result of built-up expansion, which increased surface heating and decreased local resistance to heat stress (Dutta, 2012; Pandey, 2021). Lucknow offers a dynamic case study for examining the interactions between urban form, surface temperature, and sustainable energy infrastructure (P. and S. S. Singh, n.d.). The majority of urbanisation is centred within the official boundaries of the 112 wards that make up Lucknow city, which is governed by the Lucknow Development Authority (LDA). With the exception of the Cantonment Zone (Cantt.), a defence zone designated for the Indian military, urbanisation is densest close to the city core and gradually spreads out towards the outskirts. Examining how land cover layout and green infrastructure affect local temperature variation is made easier by the city's spatial pattern, which contrasts dense built-up zones with spread green regions (Lucknow Development Authority 2023; Office of the Registrar General and Census Commissioner n.d.; Zawadzka 2021).

B. Data sets used and Preprocessing:

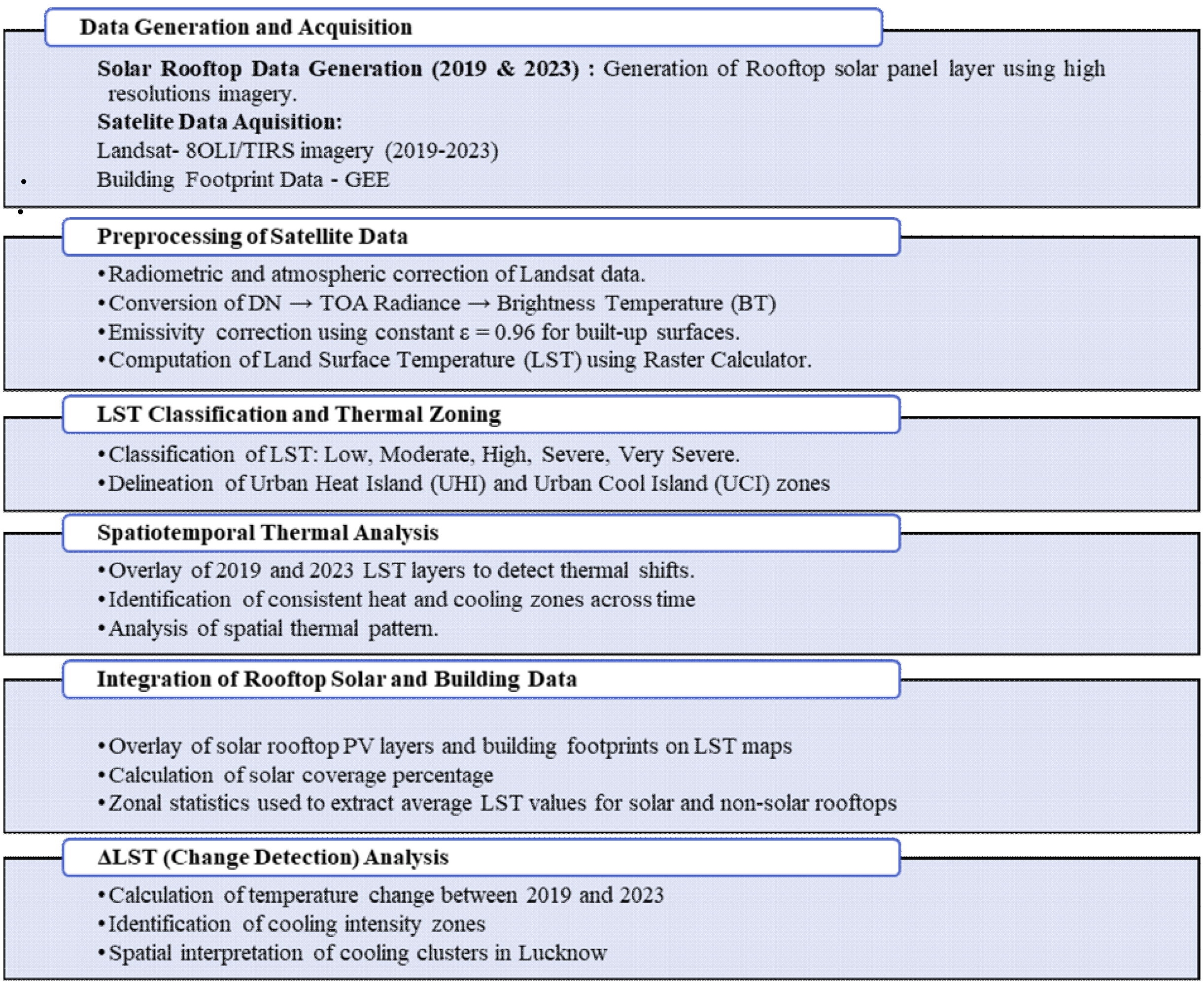

Figure 2: Overview of the research workflow

The LST and spatiotemporal temperature fluctuations near Lucknow were calculated using Landsat satellite images. Particularly, Landsat 8 (OLI/TIRS) imagery was collected on June 17, 2019, and Landsat 9 (OLI-2/TIRS-2) imagery was collected on June 12, 2023, courtesy to USGS Earth Explorer platform.

In order to secure similar atmospheric and surface conditions with minimum cloud cover, both datasets were chosen and recorded during the summer and almost for the same month. GIS software was used for all data preprocessing and LST estimates.

In order to limit the analysis to the study area, the method started by layer stacking the spectral and thermal bands with the Composite Bands tool. The images were then cropped to fit the shapefile of the Lucknow city border. GIS application was used for data preprocessing and LST estimate. The spectral and thermal bands were first layer combined using the Composite Bands tool. To be able to limit the search to the research area, the data was then clipped to the Lucknow city boundary shapefile.

The LST calculation was carried out using GIS Raster Calculator. First, the Digital Numbers (DN) from the thermal infrared band (Band 10 for Landsat 8) were transformed into Top of Atmosphere (TOA) Radiance using the radiometric rescaling factors ML and AL (included in the MTL file). The TOA radiance was then transformed into Brightness Temperature (BT) using the thermal calibration constants (K1 and K2). The brightness temperature was then converted from Kelvin to Celsius, and emissivity correction was added to determine the LST. All datasets were mapped to WGS 84/UTM Zone 44N to ensure spatial alignment. The overall methodological workflow for LST estimation and preprocessing steps is illustrated in Figure 2.

1) LST Derivation and Analysis

The LST represents the radiative skin temperature of the Earth's surface, indicating the energy exchange between the surface and atmosphere and is widely used in urban heat island (UHI) studies (Jiménez-Muñoz, 2014; Q. Weng, 2009; Q. and L. D. and S. J. Weng, 2004).

Using thermal infrared data (Band 10) through the Landsat 8 Operational Land Imager and Thermal Infrared Sensor (OLI/TIRS) images for 2019 and 2023, the LST was approximated in this work GIS software was used in all the calculations, and the Raster Calculator and map algebra tools were used.

The LST calculation involves;1: Conversion of digital number (DN) to Top-of-Atmosphere (TOA) spectral radiance, 2: then converted to Brightness Temperature (BT), and then followed by Estimation of LST after emissivity correction (U.S. Geological Survey, 2021)

Step 1: Conversion of Digital Number (DN) to Top-of-Atmosphere (TOA) Spectral Radiance

The TOA spectral radiance (Lλ) was first calculated from the Landsat 8 (Band-10) digital number (DN) values using the radiometric rescaling parameters given in the metadata file (MTL):

$L_\lambda = M_L \times Qcal + A_L$

L_λ = Top-of-Atmosphere spectral radiance (W/m²·sr·µm),

M_L = Radiance multiplicative scaling factor,

A_L = Radiance additive scaling factor, and

Qcal = Quantized calibrated pixel values (DN)

Step 2: Conversion of Spectral Radiance to Brightness Temperature

Brightness Temperature (BT) in Kelvin was calculated using the thermal constants provided in the metadata (K1 and K2):

$$BT = \frac{K2}{\ln\left(\frac{L\lambda}{K1} + 1\right)}$$

Where K1=774.8853 and K2=1321.0789 for Landsat 8 Band 10

Step 3: Correction for Land Surface Emissivity (LSE)

Since emissivity influences the amount of energy radiated by a surface, a correction was applied using an average emissivity value (ε) of 0.96, representing a composite urban surface of concrete, asphalt, and rooftops (Sobrino 2004). The final LST in Kelvin was then computed using:

$$LST = \frac{BT}{1 + \left(\frac{\lambda * BT}{\rho}\right)\ln(\varepsilon)}$$

LST = Land Surface Temperature (°C)

λ = Wavelength of emitted radiance (10.895 µm for Band 10)

$\rho = \frac{h \times c}{\sigma} = 1.438 \times 10^{-2}$ m·K (Radiation Constant)

ε = Surface emissivity

The obtained LST values were subsequently converted to degrees Celsius by subtracting 273.15. Landsat imagery of June 17, 2019, and June 12, 2023, was picked to guarantee a comparable atmospheric and surface conditions with little cloud cover. This allowed for a precise spatiotemporal analysis of surface heat variations throughout Lucknow's urban region.

2) Spatial Classification of Urban Heat and Cool Zones-2019 and 2023

The calculated LST values for 2019 and 2023 were classified into low, moderate, high, severe, and very severe temperature categories to examine spatial variability in surface thermal characteristics and the development of heat patterns across Lucknow. The classification employed the Natural Breaks (Jenks) method, a statistically based approach that minimizes variance within classes while maximizing variance between classes, thereby effectively representing local temperature differences (Estoque, 2017; Jenks, 1967)

The LST range for Lucknow in 2019 varied from 26.5°C to 39.7°C, while in 2023, it ranged from 26.2°C to 34.6°C, demonstrating a noticeable decrease in areas of intense heat. This shift raises the possibility of a cooling impact in some metropolitan areas, especially those with greener infrastructure and rooftop solar systems.

Additionally, to determine the spatial concentration and persistence of urban heat and cool zones, Kernel Density Estimation (KDE) was used to high-temperature and low-temperature zones taken from the LST categorization for 2019 and 2023. By converting clustered thermal features into continuous density surfaces, KDE made it possible to identify regions with persistent thermal intensity. Persistent coolspot clusters were seen near the Gomti River, Kukrail Reserve, and Jankipuram, indicating the moderating effects of forest cover and water bodies. Charbagh, Hazratganj, and Aminabad, on the other hand, were repeatedly identified as heat hotspot zones due to their high built-up density, scarcity of green space, and high levels of human activity.

The correlation between constructed density and surface heating patterns was confirmed by overlaying LST maps with building footprint data. While rooftop solar clusters and open parks correlated with localised cooling benefits, the concentration of hotspots in the city's commercial and transportation corridors shows a substantial association between impervious surface ratio and urban heat intensity (Li, 2013; Zhou, 2019).

3) Thermal Pattern Shifts in Lucknow (2019–2023)

The creation of multi-temporal LST surfaces made it possible to compare how the urban thermal environment of Lucknow has changed throughout time. The LST maps show a reconfiguration of surface heat regimes, where localized cooling pockets coexist with increasingly expanding heat-dominated zones, rather than serving only as static temperature representations. Comparing the thermal maps from 2019 and 2023 reveals a distinct redistribution of surface heat intensity, which reflects the combined effects of land alteration processes such urban densification, infrastructure growth, and vegetation loss. The relationship aspect of the city's thermal environment is highlighted by this spatial reconfiguration, which also offers crucial insight into new patterns of urban heat stress by highlighting locations where surface heating has increased or stabilized.

The Natural Breaks (Jenks) classification method was employed to delineate temperature zones by identifying natural groupings inherent in the LST data, minimizing variance within classes while maximizing variance between classes, thereby preserving the underlying structure of the dataset (Esri, 2021; Jenks, 1967). Low LST ranges were classified as coolspot zones, representing areas of reduced surface heating typically associated with vegetated or water-covered surfaces, whereas high LST ranges were identified as hotspot zones, corresponding to regions of elevated surface heating often linked to impervious and built-up land cover (Estoque 2017; Voogt and Oke 2003; Weng 2009).

Because of increased vegetation density and hydrological influence, the observed spatial patterns show that stable coolspot zones were mostly centered in the Kukrail Reserve Forest, the Gomti River corridor, and the Cantonment area. On the other hand, the wards of Balaganj, Faizullahganj, Indira Priyadarshini, and Shaheed Bhagat Singh were persistent and escalating hotspot locations in 2019. By 2023, these hotspots had spread to the wards of Guru Govind Singh, Sharda Nagar, Sarojini Nagar, Airport, and Raja Bijli Pasi. Increased surface sealing, decreasing vegetative cover, and continuous urban growth are all factors that contribute to the city's increased surface heat intensity. The uneven distribution of heat exposure throughout the metropolitan land is highlighted by these spatially persistent and expanding thermal patterns, which imply that some wards are growing more susceptible to chronic thermal stress. Green and blue infrastructure play a moderating function in controlling surface temperatures, as evidenced by the difference between quickly intensifying hotspot zones and stable coolspot areas. Furthermore, the observed thermal shifts indicate the cumulative effect of recent urban development trajectories, suggesting that heat stress is likely to worsen in high-density and infrastructure-dominated zones in the absence of specific mitigating measures.

These geographical insights are essential for directing climate-sensitive urban planning, especially when it comes to setting priorities for greening initiatives and heat-reduction tactics.

4) Correlation of Rooftop Solar Data with LST Patterns

Rooftop solar panel layers for 2019 and 2023 were mapped using GIS software, and building footprint data was obtained from Google Earth Engine (GEE). The percentage of rooftop coverage was then calculated by comparing the entire solar-covered rooftop area to the overall building footprint area. The following formula was used to calculate the solar rooftop coverage:

$$\text{Solar Panel Coverage (\%)} = \left(\frac{\text{Total Area of Solar Photovoltaic Panels}}{\text{Total Building Footprint Area}}\right) \times 100$$

Mean LST data were taken for each building footprint (BU_ID) using GIS Zonal Statistics as Table tool. The LST-2019, LST-2023, and related solar/non-solar attributes were exported as CSV files. The following formula was used to calculate ΔLST (change in LST) for each building unit after these CSV values were pre-processed in GIS software and Microsoft Excel in order to measure the extent of thermal change throughout Lucknow:

$$\Delta LST = LST_{2023} - LST_{2019}$$

where LST_{2023} is the LST calculated from the 2023 dataset, LST_{2019} is the 2019 dataset and ΔLST is the change in LST.

The spatial extent and energy potential of rooftop solar systems throughout the city area were estimated using the rooftop solar data, which was obtained from high-resolution satellite imagery and validated by publicly accessible renewable energy databases. Rooftop solar installations accounted for about 0.22% of all construction footprints in 2019; by 2023 that number had risen to 0.52%, exhibiting a significant increase in solar adoption in both residential and institutional buildings of Lucknow City.

The average LST values for solar-enabled and non-solar rooftops were extracted independently for both years. The assessment of ΔLST (temperature difference) between the two surface types, which represents the cooling contribution of rooftop solar systems, was made possible by this comparison. Lower temperatures over solar roofs are shown by negative ΔLST values, which can be a result of photovoltaic panel's shaded abilities that minimises the surface heating.

5) Methodological Approach for Estimating Carbon Offset and Carbon Potential

By reducing power produced from fossil fuel-based grid sources, the integration of rooftop solar energy systems provides a measurable way to reduce city greenhouse gas (GHG) emissions. Carbon offsets, or the real quantity of avoided carbon dioxide equivalent (CO_2e) emissions related to the production of renewable energy, are the consequence of this displacement. The carbon offset (CO) was calculated using the following formula:

CO (tCO_2/year) = $E_{solar} \times EF_{grid}$ (Intergovernmental Panel on Climate Change, n.d.; Ministry of New and Renewable Energy, 2022)

where E_{solar} is the annual solar energy generation (in MWh/year) and EF_{grid} is the grid emission factor (in tCO_2/MWh). According to the Central Electricity Authority (CEA, 2023), the average grid emission factor for India is roughly 0.708 tCO_2/MWh in 2023. The carbon offsets for rooftop solar generation in 2019 and 2023 were calculated using this factor, indicating the city's ability to lessen reliance on traditional power sources. One verified carbon credit is equivalent to one tonne of CO2e avoided, and these offsets can be converted to carbon credits (United Nations Framework Convention on Climate Change, 2023). These credits can be traded or monetised in voluntary or compliance markets under the Government of India's Carbon Credit Trading Scheme (Government of India, 2023), providing both monetary and eco-friendly advantages. As a result, rooftop solar adoption in Lucknow contributes to India's Nationally Determined Contributions (NDCs) under the Paris Agreement by acting as both a localised climate-cooling solution and a practical way to engage in developing carbon markets.

III. RESULTS AND DISCUSSION

A. LST Spatiotemporal Analysis (2019-2023)

Using LST obtained from Landsat 8 OLI/TIRS data for June 17, 2019, and June 12, 2023, a significant spatiotemporal reorganization of Lucknow's surface thermal environment has been observed. The spatial pattern and duration of high-temperature zones suggest an alteration of surface heat rather than uniform cooling throughout the city, even if the overall highest LST value showed a little decline from 39.0 °C in 2019 to 34.6 °C in 2023.

LST values varied from 26.5 °C to 39.0 °C in 2019 and from 26.2 °C to 34.6 °C in 2023, indicating shifts in patterns of thermal intensity brought about by changes in land use and urban surface features.

Notably in areas with more vegetation cover, open water surfaces, and rooftop solar installations, the observed reduction in peak LST values points to the establishment of local cooling effects. Major commercial corridors, highly populated residential areas, and transit networks are examples of urban areas with high imperviousness that sustained high LST values, creating noticeable urban heat hotspots.

On the other hand, coolspots with large green and open spaces were regularly found close to the Kukrail forest region, the Gomti River corridor, and the Cantonment area. Heat absorption decreased in these areas due to enhanced evapotranspiration and lower surface emissivity. In 2019, Balaganj, Faizullaganj, Indira Priyadarshini, and Shaheed Bhagat Singh wards were recognised as major hotspots in Lucknow's northeastern and central zones. New hotspot expansions near Raja Bijli Pasi, Airport, Sharda Nagar, Sarojini Nagar, and Guru Gobind Singh wards were noted by 2023, emphasising the thermal increase taken by continuous expansion of infrastructure and urban growth.

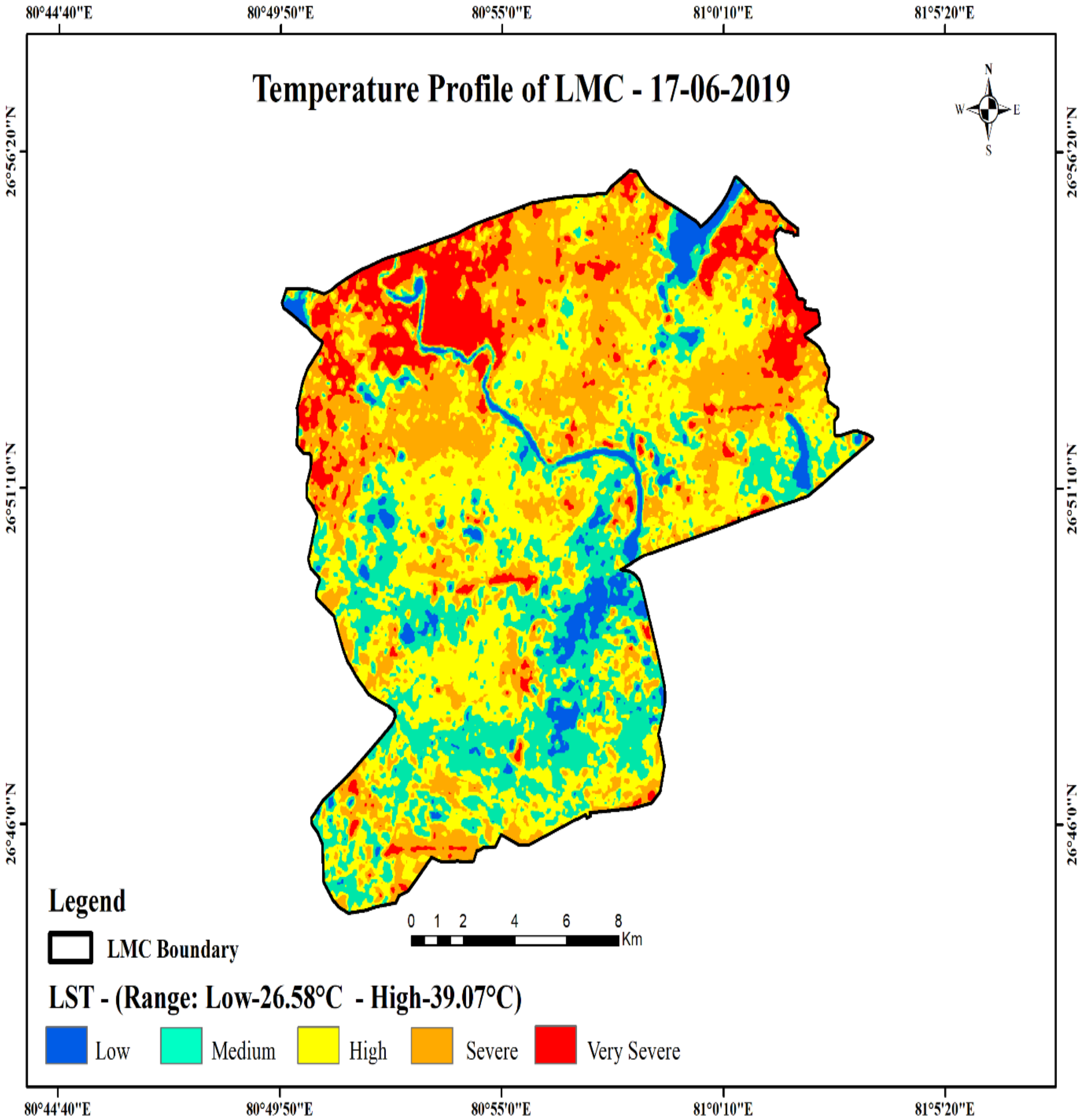

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Figure 3: LST Profile of LMC – 2019

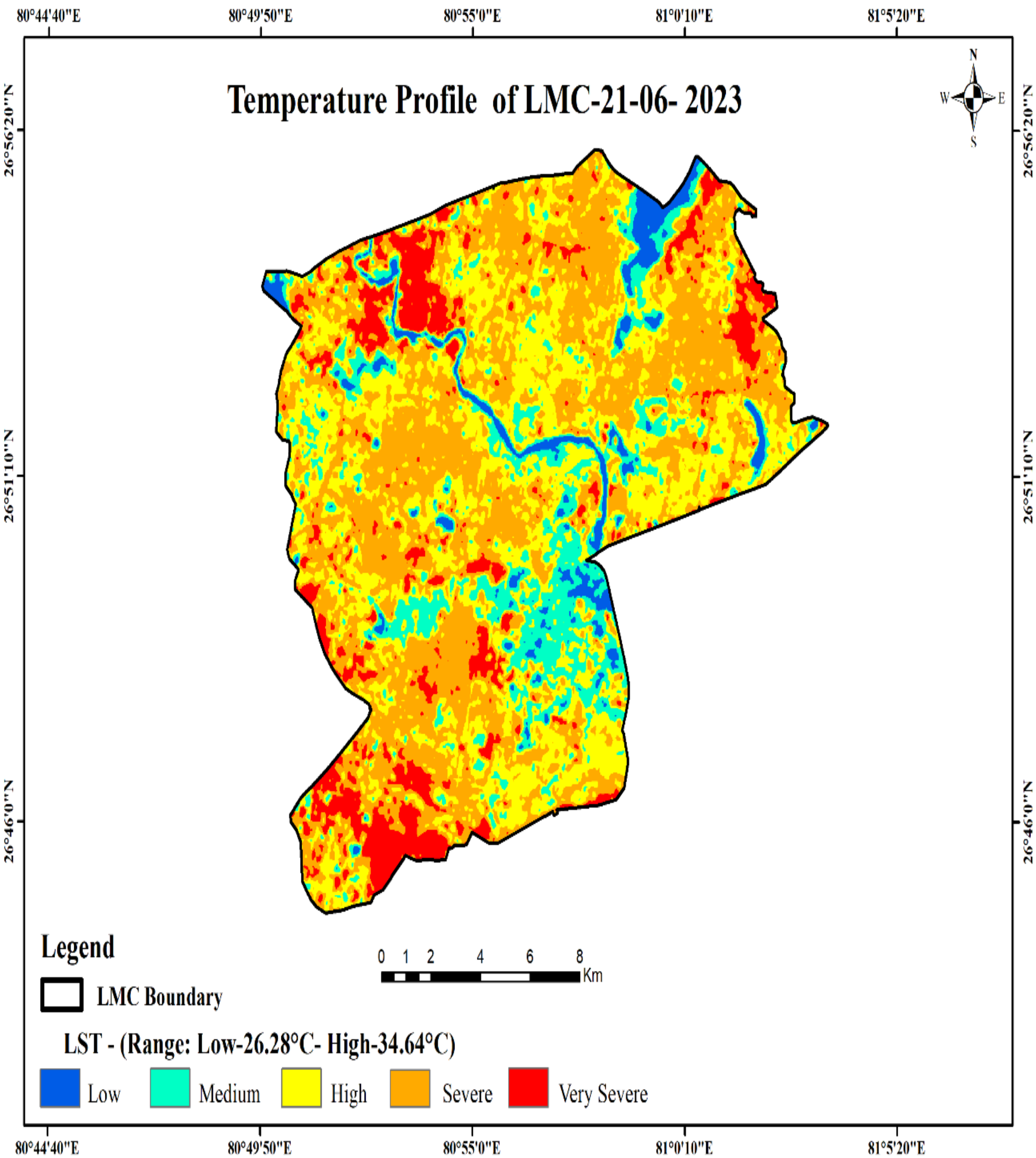

Figure 4: LST Profile of LMC – 2023

This trend is visually represented by the LST profile maps (Figure 3 and 4), which indicate a decrease in high heat zones and a rise in medium to low-temperature classes, especially in regions with enhanced rooftop solar coverage. An adaptable urban microclimate adaptation affected by solar reflective rooftops and green cover retention is suggested by the growth of cooler surfaces along the Gomti Riverfront, university campuses and vegetated residential clusters. These spatiotemporal variations show how building density and material qualities work together to produce local surface temperature gradients, highlighting the interplay of urban structure, land-use transformation, and rooftop solar integration in altering the city's thermal landscape.

B. Identification of Consistent Hotspot and Coolspot Zones (2019–2023)

GIS spatial analysis tools were used to overlay LST maps of 2019 and 2023 in order to comprehend the persistence of thermal zones across time. By identifying recurring hotspots and cool spots throughout LMC, this temporal comparison offered a dynamic view of how city thermal conditions evolved over the course of the study.

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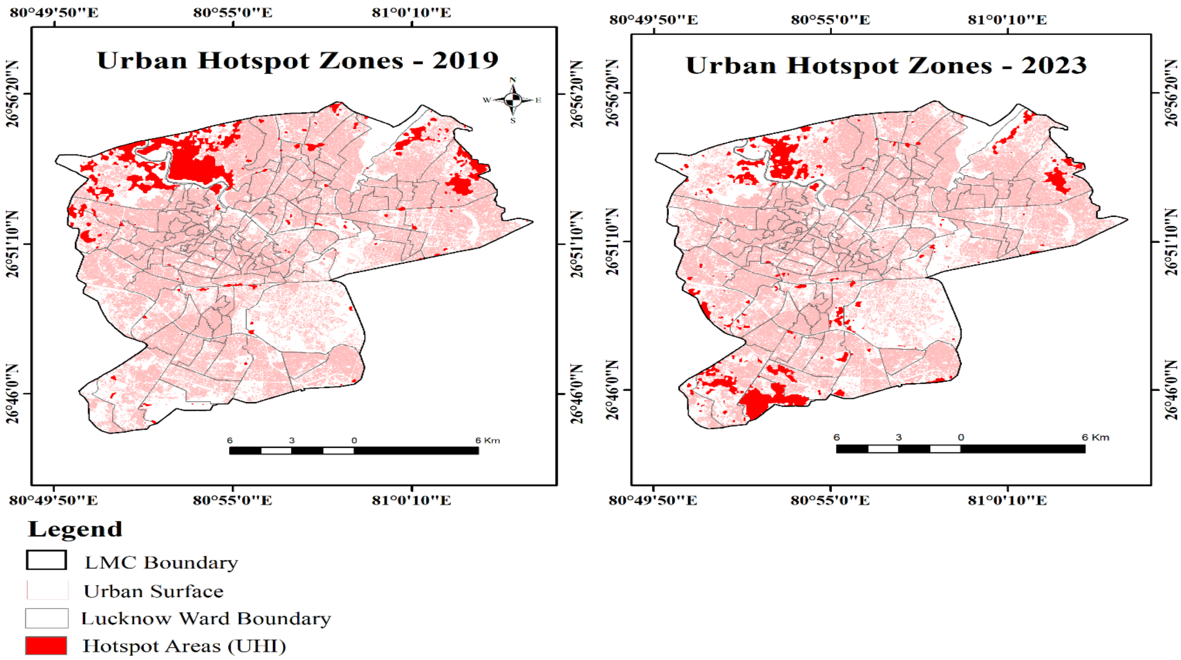

Figure 5: Spatiotemporal distribution of urban heat zones in Lucknow for 2019 and 2023

Figure 5, highlights Urban Heat Zones (UHZs) which is mainly found in the wards of Balaganj, Faizullaganj, Indira Priyadarshini, and Shaheed Bhagat Singh in 2019. By 2023, these zones had spread to cover the wards of Raja Bijli Pasi, Airport, Sharda Nagar, Sarojini Nagar, and Guru Gobind Singh. High built-up density, impermeable surface cover, and sparse vegetation are characteristics of these zones that greatly enhance solar radiation absorption and retention.

Heat retention and solar radiation absorption are greatly increased in these wards due to the predominance of high built-up density, impermeable surface materials like concrete and asphalt, less vegetation cover, and reduced open-sky aspects.

Additionally, the growth of multi stories residential areas, commercial complexes, and overcrowded roads interfering with natural circulation and changing the surface balance of energy. These spatial patterns show that the rapid, unplanned development of Lucknow and the loss of vegetative buffers have led to the extended and increased creation of UHZs, especially in recently constructed residential and industrial zones. In order to balance a city's thermal load, mitigation techniques including reflective roofing, dense greenery, and the installation of solar rooftop systems are needed in these thermally susceptible areas, which could become hotspots.

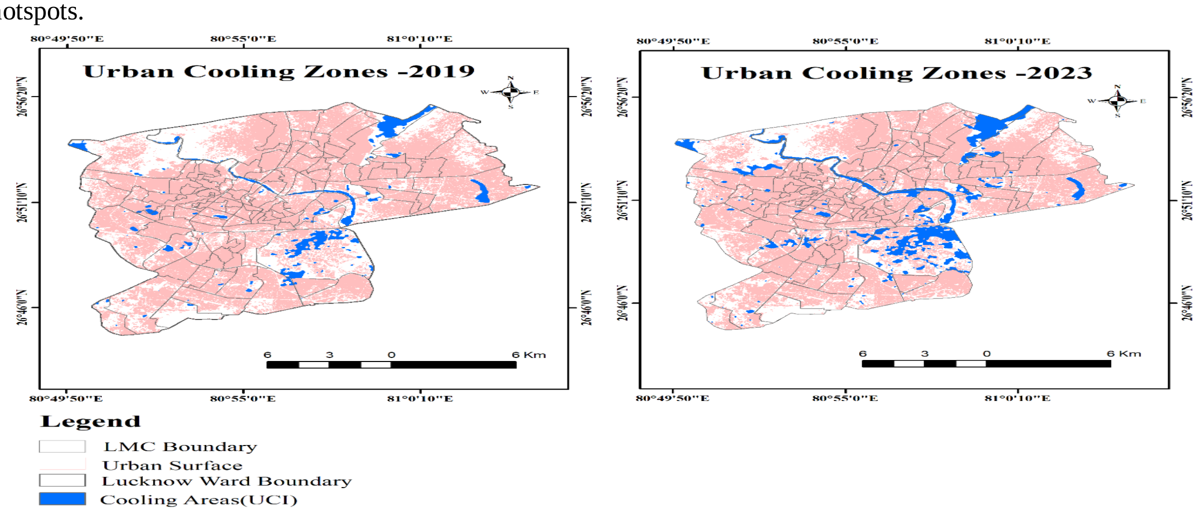

Figure 6: Spatiotemporal distribution of urban cooling zones in Lucknow for 2019 and 2023.

Figure 6 shows that the Kukrail forest region, the Gomti River corridor, and the Cantonment area are the main locations of consistent coolspot zones, where the presence of open water bodies, dense vegetation, and limited urban development all work together to maintain lower surface temperatures. These areas serve as urban thermal buffers, assisting in controlling the microclimate of the city to minimise the buildup of scorching temperatures. Lucknow's thermal environment is largely shaped by the underlying land-use pattern, building materials, and biological corridors of the city, as seen by the spatial persistence of both hotspot and coolspot zones. While areas having greenery along with open water bodies consistently show cooling benefits, areas comprised of impermeable surfaces and dense built-up constructions continue to absorb and retain heat.

The above maps demonstrate how the production of heat, absorbing, and dispersion within populations are structurally influenced by urban form and surface composition. In order to enhance resistance against heat stress and promote sustainable and balanced urban growth, future building in Lucknow should use climate-sensitive elements including solar roofs, reflecting materials, and green infrastructure.

C. Assessment of Rooftop Solar Panel Growth across Urban Built-up Regions (2019- 2023)

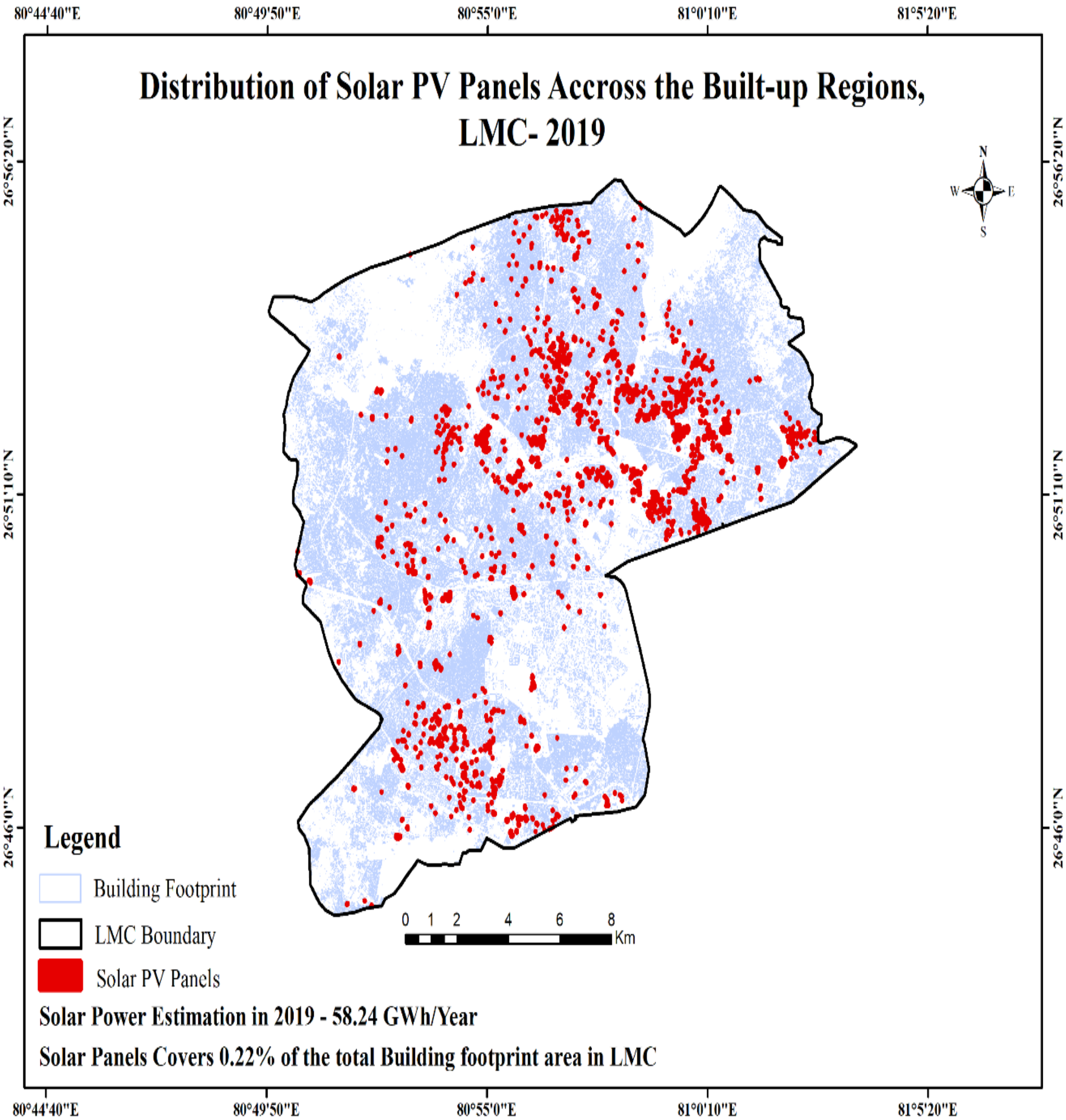

Figure 7: Solar panel distribution on building footprint in LMC (2019)

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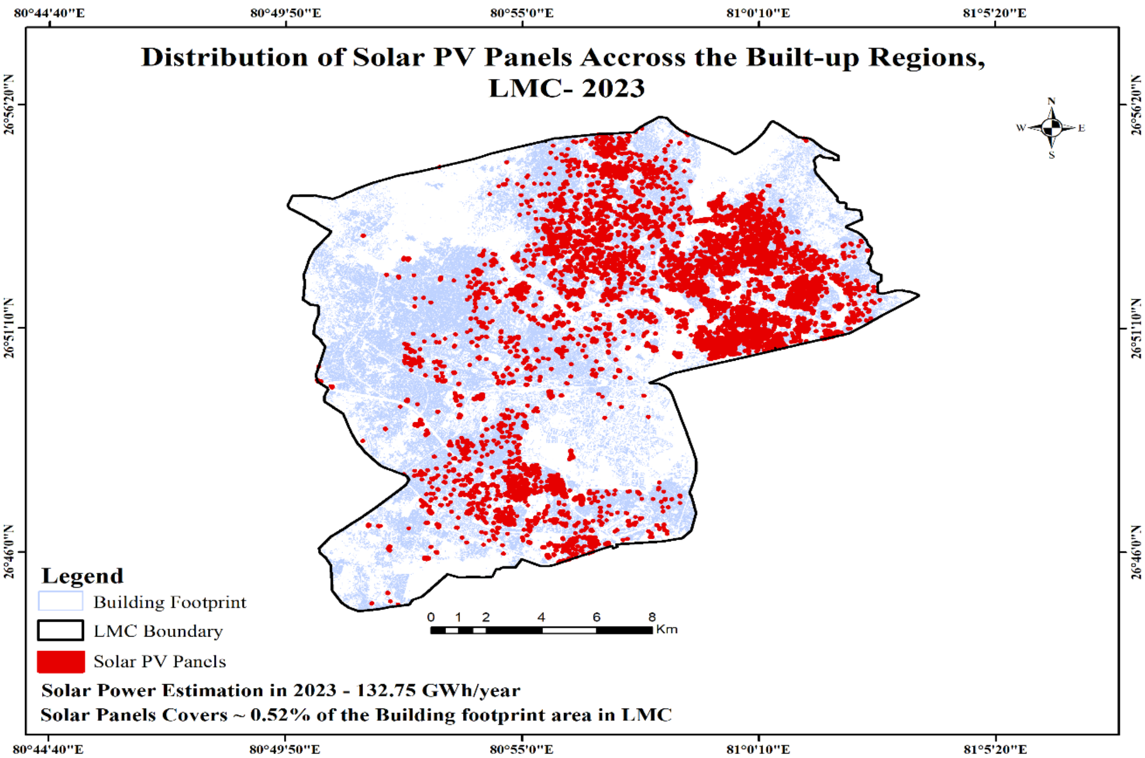


Figure 8: Solar panel distribution on building footprint in LMC (2023)

To estimate the number of installed photovoltaic (PV) modules, an average area of 1.8 m² per panel was considered, which aligns with the typical surface area of commercially available standard monocrystalline and polycrystalline solar modules ranging from 250 - 350 W capacity (International Energy Agency, 2021b; National Renewable Energy Laboratory, 2022). As a result, rooftop solar installations in Lucknow increased by a significant 131% over the course of four years, from roughly 102917 panels in 2019 to 218882 panels in 2023. The city's increasing incorporation of renewable energy sources into the built environment is exemplified by this extension.

GIS was used to integrate building footprint data and solar energy generation estimates for the years 2019 and 2023 in order to do a geographical assessment of rooftop solar installations in Lucknow. Building footprints were obtained using Google Earth Engine (GEE) using Sentinel-2 data and a threshold-based classification of built-up reflectance indices. This information served a thorough illustration of the city's structural span. The spatial distribution of rooftop solar panels in Lucknow for 2019 and 2023 is shown in Figure 7 and 8, respectively.

In 2019, Lucknow city solar adoption was still in its infancy, with little rooftop installations concentrated in Hazratganj, Aliganj, Mahanagar, Gomti Nagar and Chinhat. Rooftop solar panels produced an estimated 58.24 GWh of solar electricity annually at this time, occupying around 0.22% of the building footprint. This limited coverage represents the early stages of solar rooftop installation prior to the implementation of extensive legislative incentives and urban renewable initiatives.

Lucknow's total electricity consumption reached 5,691 million units (MWh) in 2022-23. Energy demand has continually increased due to the city's fast urbanisation and growing infrastructure. Lucknow's overall electricity consumption in 2022-2023 was 5,691 million units (MWh), according to the 20th Electric Power Survey (EPS) of India -Mega Cities Report (Central Electricity Authority, 2023). Therefore, rooftop solar production increased from 58.24 GWh/year to 132.75 GWh/year, resulting in roughly 1.02% of the entire energy use in 2019 and 2.33% in 2023. Even while it still only makes up a small percentage of overall demand, this increase demonstrates a notable upward trend in the installation of renewable energy into the city's-built environment.

Increasing the utilization of rooftop solar photovoltaic (PV) systems reduces reliance on centralized grid electricity while also helping to mitigate urban heat locally. In the present study, built-up regions with higher rooftop solar coverage exhibit slightly lower LST values than nearby non-solar zones, indicating a clear local-scale cooling effect. This thermal moderation is attributed to roof shading by PV panels and the conversion of incoming solar radiation into electricity rather than sensible heat, thereby reducing surface heat accumulation.

Beyond the thermal benefits, the increasing adoption of rooftop solar PV systems helps reduce carbon emissions by offsetting grid electricity generated primarily from fossil fuels, which remains the dominant energy source in Uttar Pradesh. Consequently, the spatial expansion of rooftop solar energy across Lucknow's built environment highlights the dual role of PV systems in enhancing urban energy sustainability and supporting localized microclimatic regulation. As a result, the continued growth of rooftop solar installations in Lucknow not only advances the city's transition toward carbon-neutral urban development but also strengthens its adaptive capacity to rising urban heat stress, particularly in residential and mixed-use built-up areas (Central Electricity Authority, 2023; Huang, 2021; Peng, 2022; Uttar Pradesh Electricity Regulatory Commission, 2023).

D. Analysis of ΔLST between 2019 to 2023

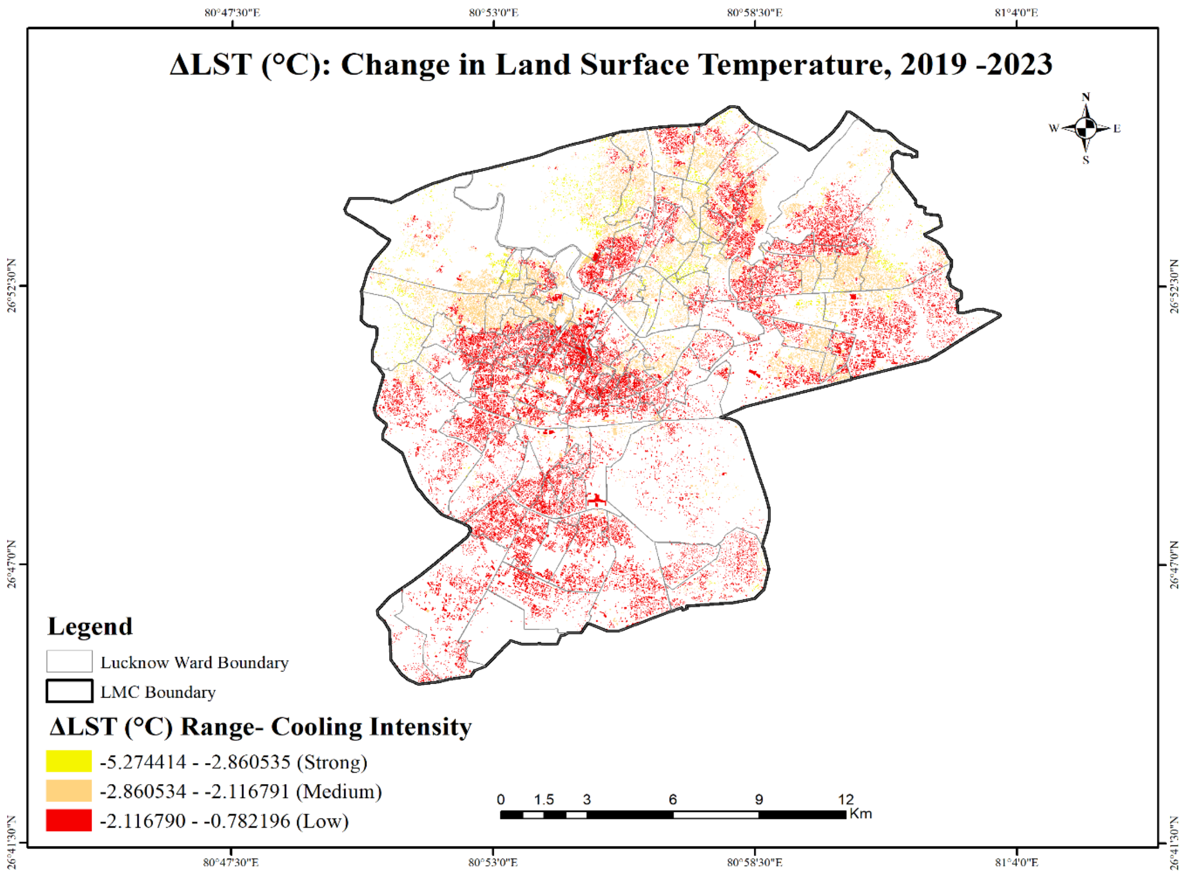


Figure 9: ΔLST Distribution Map of Lucknow: 2019–2023

ΔLST represents the change in Land Surface Temperature (°C) between 2019 and 2023, where negative values indicate surface cooling, as illustrated in Figure 9. The spatial distribution of ΔLST across Lucknow reveals a heterogeneous pattern of thermal change, indicating that cooling effects are unevenly distributed throughout the urban landscape.

Areas exhibiting strong cooling (−5.27 to −2.86 °C) appear in limited and scattered patches, primarily in zones characterized by relatively lower built-up density, vegetation cover, and open land surfaces that facilitate heat dissipation through shading and evapotranspiration. These areas demonstrate the strongest reduction in surface temperature during the study period. A large portion of the city falls within the moderate cooling category (−2.86 to −2.11 °C), particularly across mixed residential and transitional urban zones where built-up surfaces coexist with patches of vegetation and open spaces. These areas show measurable thermal improvement but still retain moderate surface heat characteristics.

In contrast, low cooling zones (−2.11 to −0.78 °C) dominate many densely built urban sectors, especially across central and southern parts of the city. These regions are characterized by high impervious surface coverage, transportation infrastructure, and limited vegetation, which restrict effective heat dissipation and result in only marginal reductions in surface temperature between 2019 and 2023.

Several wards, including Faizullah Ganj (1st and 2nd), Shaheed Bhagat Singh, Daulat Ganj, Kanhaiya Madhopur, Haidar Ganj (2nd), and Mallahi Tola (1st), fall mainly within moderate to low cooling categories. The persistence of weaker cooling in these urban zones reflects the influence of dense built-up structures and limited green cover on urban thermal dynamics.

Overall, the ΔLST pattern highlights that surface temperature reduction in Lucknow is strongly influenced by land cover composition and urban morphology. Areas with vegetation, open spaces, and lower surface sealing exhibit stronger cooling responses, while densely urban environments show relatively weaker thermal improvement. These findings underline the importance of integrating climate-sensitive urban planning measures, including increased urban greenery, reflective surfaces, and distributed renewable energy systems, to enhance thermal resilience in rapidly growing cities.

E. Estimation of Carbon Offset and Carbon Credit Potential

Through replacing grid-based power generated from fossil fuels, the growth of rooftop solar installations throughout Lucknow between 2019 and 2023 delivered tangible decreases in carbon emissions as well as to surface cooling. This formula was used to calculate the carbon offset (CO) potential in order to measure the environmental co-benefits of solar adoption:

$$CO = Esolar \times EFgrid$$

The average grid emission factor for India is 0.708 tCO_2/MWh, according to the Central Electricity Authority (CEA, 2023). According to this coefficient, Lucknow's predicted yearly rooftop solar generation was 58.24 GWh in 2019 and 132.75 GWh in 2023, resulting to avoided carbon emissions of roughly 41,635 tCO_2 and 93,487 tCO_2, respectively.

CO_{2019} = 58,240 MWh×0.708 = 41,635 tCO_2 avoided

CO_{2023} = 132,750 MWh×0.708 = 93,487 tCO_2 avoided

According to the, rooftop solar coverage increased from 0.22% to 0.52% of the total building footprint area during the four-year period, that results approximately 124.5% increase in carbon offset potential. This growth is a reflection of Lucknow's steady but important development towards an energy-resilient and urban sustainability network. Each 1 tonne of CO_2 avoided equates to one verified carbon credit (United Nations Framework Convention on Climate Change, 2023). Hence, the city’s rooftop solar generation in 2023 can yield approximately 93,000 carbon credits annually, which can be monetised or traded under the Government of India’s Carbon Credit Trading Scheme (Government of India, 2023). In spite of providing financial benefits, this offset enhances India's Nationally Determined Contributions (NDCs) under the Paris Agreement by lowering urban emissions and promoting the integration of renewable energy sources. Thus, rooftop solar is a dual-benefit technique that promotes carbon-neutral growth routes while additionally minimising urban heat through albedo and shading effects.

IV. CONCLUSION AND FUTURE SCOPE

This study used satellite-derived thermal datasets (Landsat 8 OLI/TIRS) and geospatial analysis in ArcGIS 10.8 to thoroughly assess the association between LST and rooftop solar photovoltaic (RSPV) adoption in Lucknow city from 2019 to 2023. There was an apparent decline in surface temperature throughout the urban fabric, with the maximum LST falling from 39.7°C in 2019 to 34.6°C in 2023, suggesting a slow but discernible urban cooling trend. The analysis of rooftop solar expansion shows that the total solar panel area rose by more than 131%, from 170,472.20 m² in 2019 to 393,974.23 m² in 2023. This translates to an increase from around 102,917 panels to approximately 218,882 panels, assuming an average solar module size of 1.8 m² per panel as reported by the International Energy Agency (International Energy Agency, 2021a) and the National Renewable Energy Laboratory (National Renewable Energy Laboratory, 2022). This growth decodes into an increase in clean energy output from 58.24 GWh to132.75 GWh annually, mitigating about 93,487 tonnes of CO_2 emissions annually, or 93,000 carbon credits under the Government of India's Carbon Credit Trading Scheme (Government of India, 2023) . The dual environmental role of photovoltaic (PV) systems is demonstrated by the regional association between lower LST values and rooftop solar density: thermal mitigation by lowering rooftop heat absorption and providing shade; and decrease of carbon emissions by replacing grid power derived from fossil fuels. Lucknow city 39potential to reduce carbon emissions increased in tandem with the growth in solar energy output. The carbon offset increased from 41,635 tCO_2/year in 2019 to 93,487 tCO_2/year in 2023 based on the Central Electricity Authority's (Central Electricity Authority, 2023)emission factor of 0.708 tCO_2/MWh. This is equivalent to 93,487 carbon credits that may be monetized under India's Carbon Credit Trading Scheme (CCTS, 2023). These numbers highlight rooftop solar expansion's combined environmental advantages of reduced grid dependency while decreasing localized heat accumulation.

PV systems boost microclimatic cooling through energy conversion, shading, and decreased heat storage on built-up surfaces, as established by spatial overlay analysis, which showed that locations with higher rooftop solar density showed comparatively lower mean LST values.

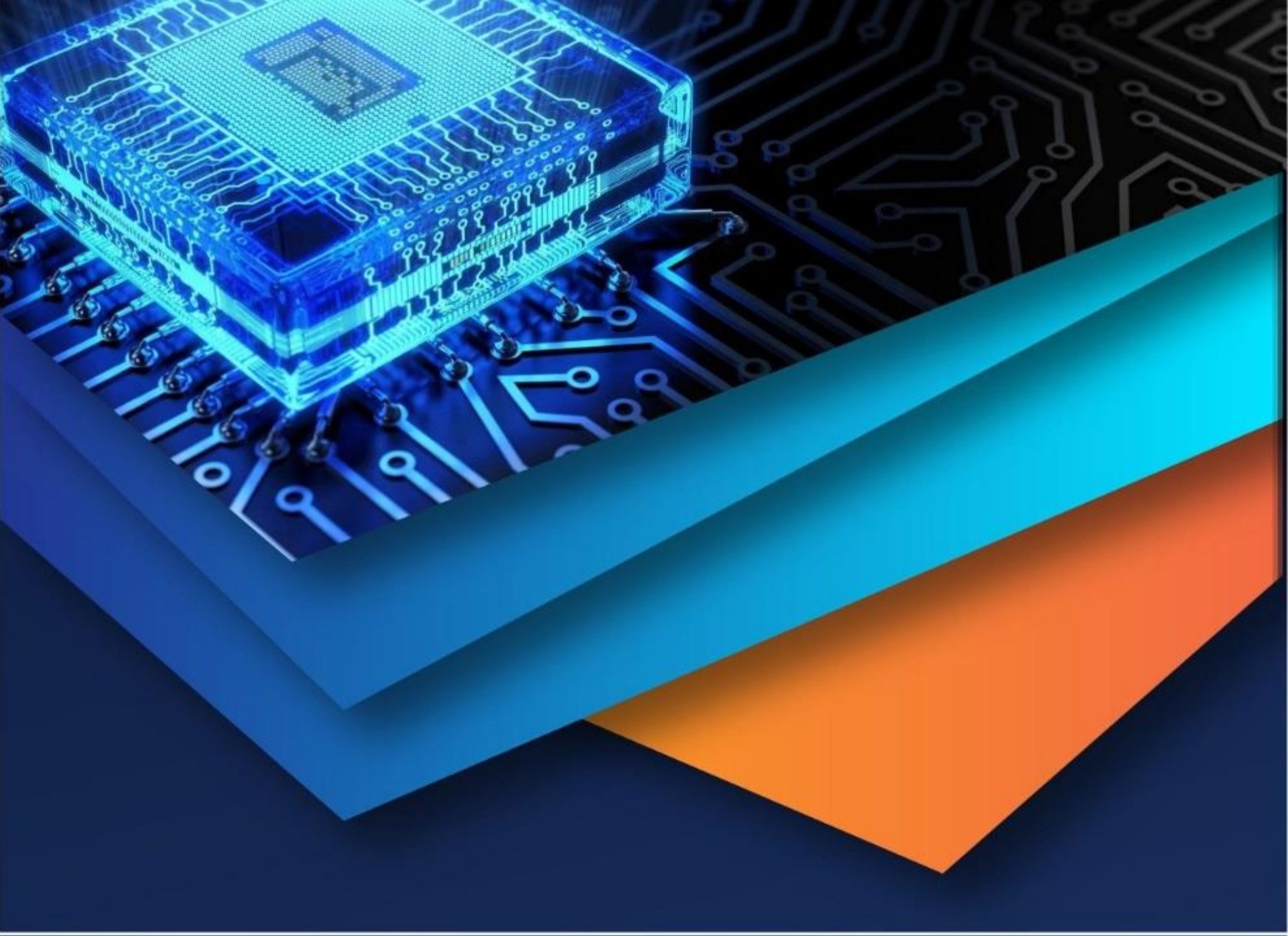
On the other hand, thermally persistent areas like Balaganj, Faizullaganj, and Charbagh still have high surface temperatures, which highlights the need to expand the use of solar panels, reflective roofs, and green spaces in busy commercial regions. According to the ΔLST map, Lucknow's cooling impacts are spatially diverse, with the southern and southwest regions of the city seeing the strongest cooling. Wards in the vicinity of Alambagh, Charbagh periphery zones, Sarojini Nagar, Raja Bijli Pasi, and residential areas near the airport show moderate to high cooling, with ΔLST values between −3.54 °C and −2.54 °C, and in isolated pockets reaching ≤ −4.5 °C (very strong cooling). Clustered rooftop solar arrays and relatively lower building densities, which improve shading and decrease surface heat storage, are characteristics of these places.

Overall, the research suggests convincing evidence that rooftop solar adoption serves as an approach for both adaptation and mitigation of climate change, concurrently reducing urban heat and offsetting carbon emissions. Sustainable Development Goals SDG 9 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action) are all in line with these research results. Lucknow serves as an example for mid-sized Indian city that want to move toward carbon-neutral, thermally resilient urban systems by encouraging targeted renewable energy. In order promote data-driven urban planning, climate-sensitive design, and low-carbon growth paths for the future, the approach that was created for Lucknow can be used to other Indian metropolitan areas.

REFERENCES

[1] Central Electricity Authority. (2023). CO_2 Baseline Database for the Indian Power Sector (Version 18).
[2] Chow, W. (2012). Urban Heat Island Research in Phoenix, Arizona: Theoretical Contributions and Policy Applications. Bulletin of the American Meteorological Society.
[3] CPCB. (2023). National Air Quality Status & Trends Report 2023. Central Pollution Control Board, Government of India.
[4] Dutta, V. (2012). Land Use Dynamics and Peri-urban Growth Characteristics: Reflections on Master Plan and Urban Suitability from a Sprawling North Indian City. Environment and Urbanization Asia, 3, 277–301. 10.1177/0975425312473226
[5] Esri. (2021). ArcGIS Desktop: Release 10.8
[6] Estoque, R. C. and M. Y. and M. S. W. (2017). Effects of landscape composition and pattern on land surface temperature: An urban heat island study in the megacities of Southeast Asia. Science of the Total Environment, 577, 349–359.
[7] G. Darrel Jenerette, S. L. H. W. L. S. C. A. M. (n.d.). Ecosystem services and urban heat riskscape moderation: water, green spaces, and social inequality in Phoenix, USA. Ecological Applications.
[8] Government of India. (2022). India’s Third Biennial Update Report to the United Nations Framework Convention on Climate Change (UNFCCC).
[9] Government of India. (2023). Carbon Credit Trading Scheme, 2023. https://beeindia.gov.in
[10] Gupta, R. and P. A. (2020). Urban expansion and vegetation loss in Lucknow city: A remote sensing-based assessment. Environmental Monitoring and Assessment, 192, 1–15.
[11] Gupta, U. (2025). India installed 17.4 GW utility-scale solar, 5.15 GW rooftop PV capacity in FY 2025: JMK Research. PV Magazine India. https://www.pv-magazine-india.com/2025/07/08/india-installed-17-4-gw-utility-scale-solar-5-15-gw-rooftop-pv-capacity-in-fy-2025-jmk-research
[12] Huang, Y. , L. Y. , & Z. X. (2021). Impacts of rooftop solar photovoltaic installations on urban surface temperature: A remote sensing assessment. Renewable Energy, 1226–1237.
[13] India Meteorological Department. (2023). Climatological Normals of Lucknow (1981--2010).
[14] Intergovernmental Panel on Climate Change (IPCC). (2021). Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://www.ipcc.ch/report/ar6/wg1/
[15] Intergovernmental Panel on Climate Change (IPCC). (2022). Climate Change 2022: Mitigation of Climate Change
[16] Intergovernmental Panel on Climate Change. (n.d.). 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy .
[17] International Energy Agency, I. (2023). World Energy Outlook 2023. www.iea.org/terms
[18] International Energy Agency. (2021a). Average Solar Photovoltaic Module Sizes and Efficiency Trends.
[19] International Energy Agency. (2021b). Solar PV Technology and Market Update.
[20] International Energy Agency. (n.d.). Renewables 2021: Analysis and forecast to 2026.
[21] Jenks, G. F. (1967). The data model concept in statistical mapping. International Yearbook of Cartography, 7, 186–190.
[22] Jiménez-Muñoz, J. C. , S. J. A. , S. D. , M. C. , & C. J. (2014). Land surface temperature retrieval methods from Landsat-8 thermal infrared sensor data. IEEE Geoscience and Remote Sensing Letters, 11.
[23] Khan, A., Anand, P., Garshasbi, S., Khatun, R., Khorat, S., Hamdi, R., Niyogi, D., & Santamouris, M. (2024). Rooftop photovoltaic solar panels warm up and cool down cities. Nature Cities, 1(11), 780–790. https://doi.org/10.1038/s44284-024-00137-2
[24] Khan, S. and A. R. and P. P. (2024). Urban Expansion and Spatial Growth Patterns in Lucknow, India (1991--2021). Sustainability, 17, 227. https://doi.org/10.3390/su17010227
[25] Kikon, N. and S. P. and S. S. K. and V. A. (2016). Cooling effects of urban parks on land surface temperature in urban environments. Urban Forestry & Urban Greening, 20(2016), 220–229.

[26] Li, X. and Z. Y. and A. G. R. and I. M. and L. S. (2013). Urban heat island and land surface temperature relationships with land use and land cover changes. Remote Sensing of Environment, 128, 1–10.
[27] Lucknow Development Authority. (2023). Lucknow Master Plan 2031.
[28] Lucknow Municipal Corporation. (2023). City Profile and Administrative Boundaries of Lucknow.
[29] Ministry of New and Renewable Energy. (2022). Grid Emission Factor for the Indian Power Sector.
[30] Ministry of New and Renewable Energy. (2023). Annual Report 2022--23: Accelerating India's renewable energy transition.
[31] National Renewable Energy Laboratory. (2022). Solar Photovoltaic Technology Basics.
[32] Office of the Registrar General and Census Commissioner, I. (n.d.). District Census Handbook: Lucknow, Uttar Pradesh.
[33] Pandey, P. and K. D. and R. A. (2021). Monitoring land use--land cover change and its impact on land surface temperature in Lucknow city using geospatial techniques. Arabian Journal of Geosciences, 14, 1964.
[34] Peng, J. W. Y. L. Y. W. J. L. S. (2022). Cooling potential of rooftop photovoltaic systems in urban environments: Implications for urban heat mitigation. Applied Energy, 306.
[35] Rashid, N. (2022). Impact of land use change and urbanization on urban heat island intensity. Environmental Challenges, 8, 100571.
[36] Renewable Energy Agency, I. (2022). RENEWABLE ENERGY STATISTICS 2022 STATISTIQUES D'ÉNERGIE RENOUVELABLE 2022 ESTADÍSTICAS DE ENERGÍA RENOVABLE 2022 About IRENA. www.irena.org
[37] Renewable Energy Policy Network for the 21st Century. (2023). Renewables 2023: Global Status Report (GSR 2023).
[38] Santamouris, M. (2014). Cooling the cities ─ A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. Solar Energy.
[39] Sarif, M. O., & Gupta, R. D. (2019). Land Surface Temperature Profiling and its Relationships with Land Indices: A Case Study on Lucknow City. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 4(5/W2), 89–96. https://doi.org/10.5194/isprs-annals-IV-5-W2-89-2019
[40] Sharma, D. and S. R. and A. A. (n.d.). Assessing urban heat island intensity and land surface temperature variations in Lucknow using multi-temporal Landsat data. Sustainable Cities and Society, 76.
[41] Singh, P. , & G. A. (2021). Urbanization patterns and environmental impacts in the Lucknow metropolitan region. Journal of Urban Management, 10(2), 145–155
[42] Singh, P. and K. P. (2021). Urban growth and land use land cover change analysis of Lucknow city using remote sensing and GIS. Journal of Urban Management, 10, 243–257.
[43] Singh, P. and S. S. (n.d.). Evaluating urban expansion and land surface temperature dynamics using geospatial techniques: A case study of Lucknow city, India. Environmental Monitoring and Assessment, 195, 543.
[44] Sobrino, J. A. ; J.-M. J. C. ; P. L. (2004). Land surface temperature retrieval from LANDSAT TM 5. Remote Sensing of Environment, 90, 434–440.
[45] U.S. Environmental Protection Agency. (2008). Reducing Urban Heat Islands: Compendium of Strategies - Green roofs. https://www.epa.gov/heat-islands/heat-island-compendium.
[46] U.S. Geological Survey. (2021). Landsat 8 (L8) Data Users Handbook.
[47] Uma Singh, & Sarika Shukla. (2023). Spatio-Temporal Analysis of Urban Heat Island Using Remote Sensing and GIS in Lucknow City, Lucknow District, U.P. (2002-2020). World Wide Journal of Multidisciplinary Research and Development.
[48] United Nations Framework Convention on Climate Change. (2023). The Clean Development Mechanism and Carbon Credit Framework.
[49] Uttar Pradesh Electricity Regulatory Commission. (2023). Annual Performance Review of Power Utilities in Uttar Pradesh. https://www.uperc.org/
[50] Voogt, J. A., & Oke, T. R. (2003). Thermal remote sensing of urban climates. Remote Sensing of Environment, 86(3), 370–384. https://doi.org/10.1016/S0034-4257(03)00079-8
[51] Weng, Q. (2009). Thermal infrared remote sensing: Sensors, methods, applications. In Q. and Q. D. A. Weng (Ed.), Advances in Environmental Remote Sensing: Sensors, Algorithms, and Applications (pp. 162–188). CRC Press.
[52] Weng, Q. and L. D. and S. J. (2004). Estimation of land surface temperature--vegetation abundance relationship for urban heat island studies. Remote Sensing of Environment, 89, 467–483.
[53] Zawadzka, J. and H. D. and W. M. (2021). Linking urban green infrastructure to land surface temperature—A systematic review. Landscape and Urban Planning, 214
[54] Zhang, Y. , M. A. T. , & T. B. L. (2021). The luxury effect in urban heat: Spatial and temporal patterns of land surface temperature in relation to socioeconomic factors. Science of the Total Environment.
[55] Zhou, D. and Z. S. and Z. L. and L. S. and S. G. (2019). The footprint of urban heat island effect in China. Scientific Reports, 9, 2147. https://doi.org/10.1016/j.rse.2012.12.018



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