Government of Tamil Nadu
State Planning Commission

URBAN HEAT ISLAND- HOTSPOT ANALYSIS AND MITIGATION STRATEGIES FOR TAMIL NADU

2024

TAMIL NADU STATE LAND USE RESEARCH BOARD
STATE PLANNING COMMISSION

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TAMIL NADU
STATE PLANNING
COMMISSION

Collaborations

The Tamil Nadu State Land Use Research Board (TNSLURB) is a permanent entity within the State Planning Commission, established in 2011 to conserve land and water resources through sustainable utilization. It integrates modern geospatial technology with traditional methods to develop data-driven decision support systems, promoting informed land use policies and planning.

The United Nations Environment Programme (UNEP) leads global efforts to address environmental challenges and promote sustainable development. UNEP's Cool Coalition is an initiative to improve cooling efficiency worldwide, helping reduce greenhouse gas emissions and combat climate change by promoting sustainable cooling solutions.

CEPT University in Ahmedabad is renowned for its focus on sustainable architecture and design education. Through its CARBSE center, the university advances research in energy efficiency, innovative building technologies, and sustainable urban solutions.

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Acknowledgement

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FOREWORD

VICE CHAIRMAN

STATE PLANNING COMMISSION

Dr. J. Jeyaranjan

Tamil Nadu's urban areas, especially in densely populated cities like Chennai, face major challenges from rapid urbanization, climate change, and increasing risks to disasters. Heat is a serious invisible disaster. Urban Heat Island Effect (UHIE) is a phenomenon where urban areas experiencing significantly higher temperatures than surrounding rural regions due to human activity, extensive buildings, and limited green spaces. This effect intensifies heat levels, impacting public health, increasing energy demand, and reducing urban comfort.

Our State is dedicated to addressing these impacts through a comprehensive strategy, including the pioneering step of notifying heat as a state specific disaster. Early in 2024, the State Planning Commission had prepared a report on Tamil Nadu Heat Mitigation Strategy. Further, to support urban resilience, the State Planning Commission, through the Tamil Nadu State Land Use Research Board, has been conducting extensive studies. This is one of the notable studies, supported by United Nations Environment Programme (UNEP), and CEPT University, focuses on analyzing Urban Heat Island vulnerability. The findings identify vulnerable hotspots across Tamil Nadu and recommends targeted adaptive interventions, fostering a more integrated approach to urban resilience in the state. This strategic approach enables the State in prioritization of resources and targeted adaptation measures in the most affected regions, ensuring a proactive and focused response to climate change challenges.

EXECUTIVE SUMMARY

The intensifying heat resulting from climate change presents serious risks to health, food security, water availability, and economic productivity. The 2024 report, Countdown on Health and Climate Change, published by The Lancet, highlights the increasing health threats associated with climate change worldwide, with India among the most severely impacted. In response to these escalating risks, the Tamil Nadu State Planning Commission with the Tamil Nadu State Land Use Research Board, in collaboration with the United Nations Environment Programme, and CEPT University, has developed the "Urban Heat Island - Hotspot Analysis and Mitigation Strategies for Tamil Nadu" offering a structured approach to understanding & reducing urban heat impacts. The report builds upon the foundation laid by the Tamil Nadu Heat Mitigation Strategy, which highlights the intensifying challenges posed by extreme and prolonged heat waves in the state. With temperatures frequently exceeding the comfortable range of 25-30ºC at 60% humidity, Tamil Nadu's population, ecosystems, and infrastructure are increasingly vulnerable to heat stress. Nearly 59% of the population experiences temperatures above 35ºC, underscoring the urgency of heat resilience measures as climate change heightens these risks. To address these challenges, Tamil Nadu has established the Heat Action Network to facilitate inter-departmental and intersectoral collaboration, ensuring an evidence-driven and comprehensive response to heat mitigation.

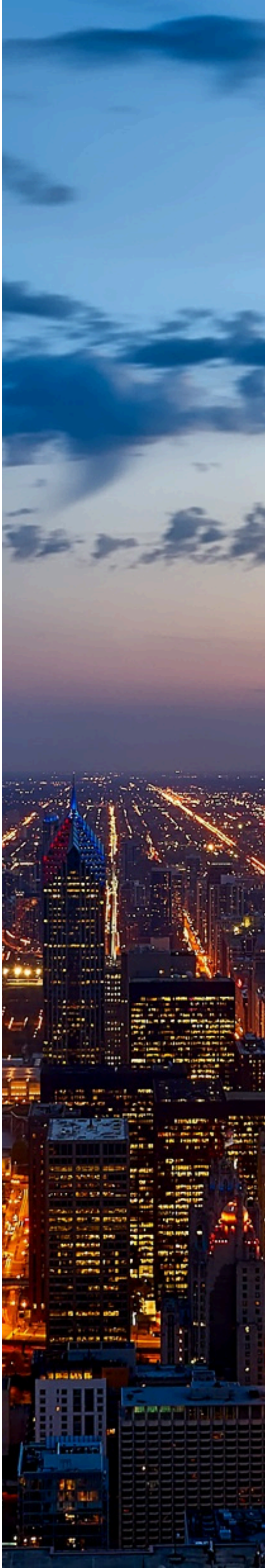
The Urban Heat Island - Hotspot Analysis and Mitigation Strategies report provides a focused analysis of Urban Heat Island (UHI) effects across Tamil Nadu, identifying the areas where urbanization and climate change intersect to create localized heat stress. The report consists of two primary components: "State-level and District-level urban heat zones" and "City-level hotspot analysis." followed by recommendations for mitigation. The first part offers a statewide perspective, mapping heat zones across Tamil Nadu to pinpoint high-risk areas and guiding future land use planning. By creating a district-level heat map, the report aims to help Tamil Nadu plan strategically for urban resilience, targeting resources and interventions where they are most needed.

Over the past 20 years, the report notes a trend of increasing night-time temperatures in Tamil Nadu, with a 59% rise in areas experiencing night temperatures of 24-26°C, while extreme daytime temperatures (46-50°C) have decreased by 28%. This pattern suggests that dense urban areas, particularly Chennai, retain heat overnight, intensifying Urban Heat Island (UHI) effects. Key hotspots include Thoothukkudi, which records the highest daytime temperatures, and Chennai, significantly affected by increased night-time heat. UHI intensity has risen by nearly 3°C in cities like Chennai and Thiruvallur, driven by dense urban development and reduced green cover.

The second component, Identification and Assessment of Hotspots Across Urban Areas of Tamil Nadu and followed by Recommendations for Managing UHIE Mitigation, maps UHI hotspots across the state using land classifications—built-up areas, vegetation, water bodies, and barren land. Employing Land Use and Cover (LULC) indicators, the analysis reveals how urbanization affects surface temperatures. Temporal analysis from 2013 to 2023, using landscape indices such as NDVI (vegetation), NDBI (built-up), and MNDWI (water), shows that urban expansion heightens UHI effects, especially in Thoothukkudi, Chennai, and Madurai, where reduced green spaces and increased construction have raised night-time temperatures.

City-specific assessments reveal varied temperature distributions tied to land characteristics, with Madurai's dense urban areas correlating with higher temperatures, while coastal Thoothukkudi shows temperature ranges influenced by natural heat sinks.

To mitigate UHI effects, the report recommends increasing urban green cover through forestry and green corridors, adopting cool pavements and reflective materials, and restoring natural heat sinks like water bodies. At the building level, climate-sensitive designs, green roofs, and energy-efficient materials are advised. Integrated into planning and building codes, these measures aim to systematically reduce urban thermal stress. Chapter 4 underscores continued collaboration through the Heat Action Network and highlights Tamil Nadu State Land Use Research Board initiatives for climate resilience and sustainable urban development.



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Abbreviations

BHEL	Bharat Heavy Electricals Limited
CARBSE	Centre for Advanced Research in Building Science & Energy
CEPT	Centre for Environmental Planning and Technology
CMA	Chennai Metropolitan Area
CRDF	CEPT Research and Development Foundation
FSI	Floor space index
FSI	Floor space index
HVAC	Heating, ventilation, and Air Conditioning
IMD	India Meteorological Department
LAI	Leaf Area Index
LANDSAT	Land Satellite
LANDSAT	Land Satellite
LID	Low-impact development
LST	Land Surface Temperature
LST	Land Surface Temperature
LULC	Land Use Land Cover
LULC	Land Use Land Cover
MNDWI	Modified Normalized Difference Water Index
MODIS	Moderate Resolution Imaging Spectroradiometer
MODIS	Moderate Resolution Imaging Spectroradiometer
NDBI	Normalized Difference Built-up Index
NDVI	Normalized Difference Vegetation Index
NMT	Non-motorized transport
PET	Physiological Equivalent Temperature
PRECIS	Providing Regional Climates for Impacts Studies
SDMA	State Disaster Management Authority
SRI	Solar Reflectance Index
SUHI	Surface Level UHI
TIRS	Thermal Infrared Sensor
TNGCC	Tamil Nadu Green Climate Company
TNSLURB	Tamil Nadu State Land Use Research Board
TP	Town Planning
UHI	Urban Heat Island
UHI	Urban Heat Island
UHIE	Urban Heat Island Effect
UHIE	Urban Heat Island Effect
UNEP	United Nations Environment Programme

CHAPTER 1

HEAT HAZARD & URBAN HEAT ISLAND EFFECT – NEED FOR MITIGATION

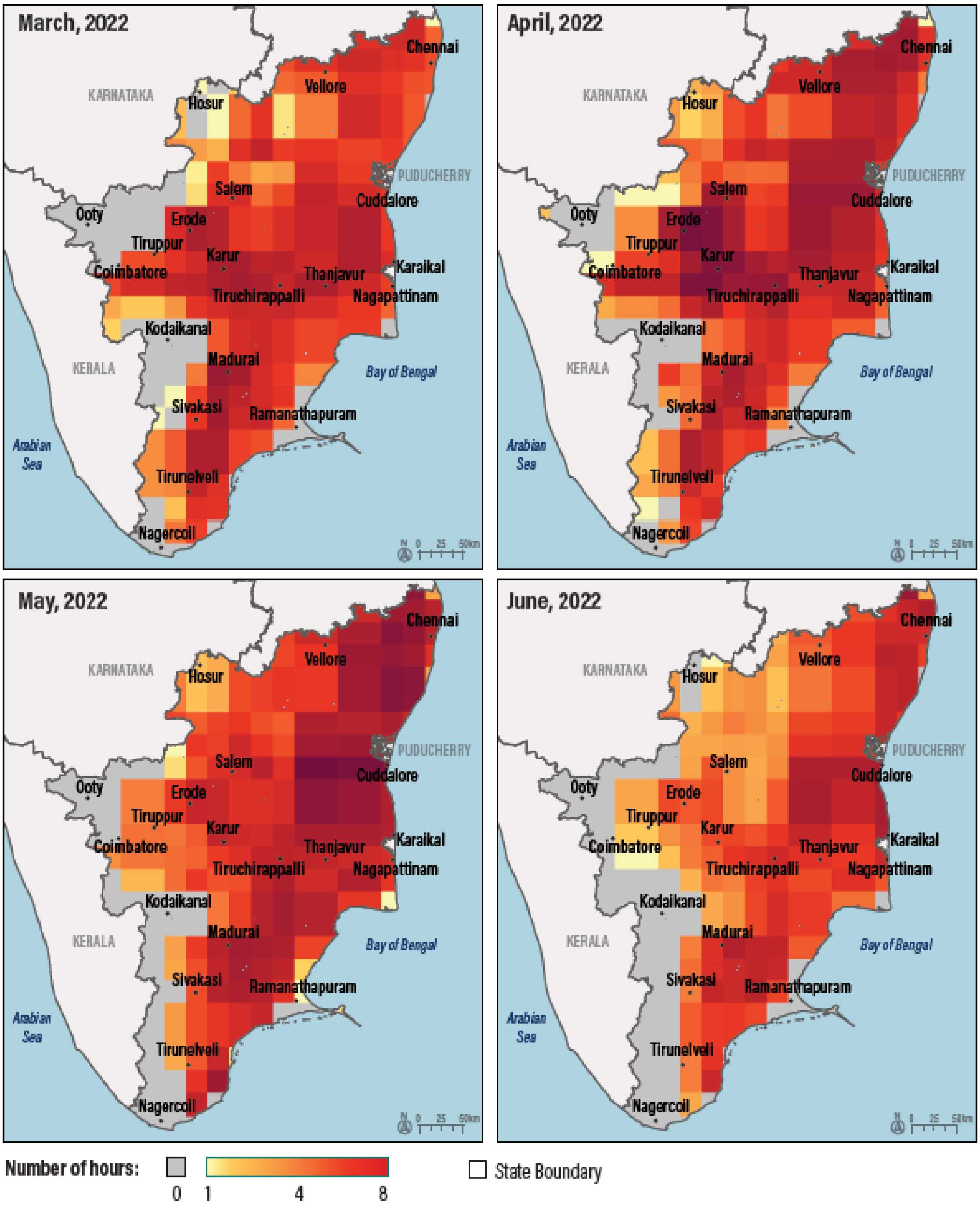
1. HEAT HAZARD & URBAN HEAT ISLAND EFFECT – NEED FOR MITIGATION

The Intergovernmental Panel on Climate Change's Sixth Assessment Report (IPCC AR6) highlights the rising risks of severe heat stress, compounded by drought, water scarcity, forest fires, and tropical cyclones. These conditions are expected to lead to a 1,540% increase in health-related deaths among people over 65 by 2090, with India projected to face an additional 1 million heat-related deaths if warming continues unchecked. Additionally, the international Labour Organization (ILO) estimates that India lost 4.3% of working hours to heat stress in 1995, a figure expected to rise to 5.8% by 2030, equivalent to the loss of 34 million jobs. Intensifying heat from climate change poses significant threats to health, food security, water availability, and economic productivity. The 2024 report titled 'Countdown on Health and Climate Change' published by *The Lancet,* has found increasing health risks from climate change in most countries, with India being one of the most impacted. Further, the report notes that 10 of the 15 indicators it uses for monitoring climate change-related health hazards globally have reached "concerning new records". It also reports that in India, besides the risk of heat-related diseases, the report has flagged potential health impacts from rising instances of flooding, increasing vulnerability from infectious diseases, and high levels of air pollution, all of which are getting exacerbated due to climate change. But the biggest risk, according to the report, is from heat because of which about 181 billion potential labour hours were lost last year, an increase of 50% from the 1990-1999 annual average.

With respect to health, heat is becoming an escalating concern across India, with significant mortality from heat waves since the 2010s. From 2011 to 2018, 6,187 heat-related deaths were reported, likely an undercount (CDKN, 2021). India began addressing heat as a disaster management issue in 2015, guiding states, districts, and local bodies to ensure preparedness and response. Collaborative efforts by the India Meteorological Department (IMD), National Disaster Management Authority (NDMA), and regional bodies have led to Heat Action Plans (HAPs) in 23 states, including Tamil Nadu. These plans provide frameworks for preventive measures, emergency aid, and treatment protocols, supported by five-day temperature forecasts.

However, significant gaps exist in HAPs, as noted in multiple studies. Key issues include the lack of localized, context-specific measures for heat mitigation, limited community involvement, insufficient targeting of vulnerable groups, and inadequate financing for effective implementation. Additionally, HAPs have weak legal backing and address sectoral needs in isolation, limiting their effectiveness in managing the complex, interconnected impacts of heat stress on health, ecosystems, and productivity. Prolonged heat exacerbates food insecurity and heightens human-animal conflicts, disproportionately affecting vulnerable populations (Centre for Policy Research, 2023).

Tamil Nadu, located in southern India, experiences a tropical climate that makes it highly susceptible to heat stress. Despite being bordered by the sea and the Western Ghats, the state regularly endures temperatures over 40°C for significant portions of the year. Studies predict that both temperatures and heat stress levels will continue to rise in coming years. Between 2011 and 2021, Tamil Nadu averaged more than eight heat wave days annually, and in 2023, 12 heat-related deaths were reported by June alone. Health impacts are often under-reported or unrecognized, especially among vulnerable groups who may lack resources or awareness to report heat-related health issues.



Source: Universal Thermal Comfort Index (UTCI), Climate Data Store (CDS), Copernicus EU; 2022. Refer to Annexure A1 for details.

Note: The average number of hours are derived using hourly UTCI data, categorised as Very Strong and Extreme heat stress for 2022.

Figure 1: Average number of hours spent under very strong to extreme strong heat stress in Tamil Nadu from March to June 2022

1.1 URBAN HEAT ISLAND EFFECT

In urbanized regions, the Urban Heat Island (UHI) effect intensifies warming trends, with cities like Chennai, Coimbatore, and Madurai experiencing average night-time land surface temperatures of approximately 26°C. The causes of this heat retention are complex: urban density, loss of vegetative cover, and the thermal properties of building materials collectively contribute to a warmer urban microclimate. The UHI effect leads to elevated temperatures that particularly impact low-income and vulnerable populations who often lack sufficient access to cooling resources, exacerbating health and environmental inequalities.

The UHI effect, commonly referred to as the "heat island effect," arises because urban areas are generally warmer than surrounding rural landscapes. This temperature difference is largely due to the transformation of natural ground cover into built surfaces such as asphalt, concrete, and buildings. These surfaces have lower albedo, or reflectivity, and thus absorb and retain more solar energy, reducing the natural shade and cooling effects typically provided by vegetation. Additionally, urban areas with limited greenery have lower rates of evapotranspiration, which would otherwise dissipate heat. The thermal properties of urban materials, particularly their solar reflectance, thermal emissivity, and heat capacity, are fundamental to the UHI effect as they determine how much sunlight is absorbed, emitted, or retained within the city environment.

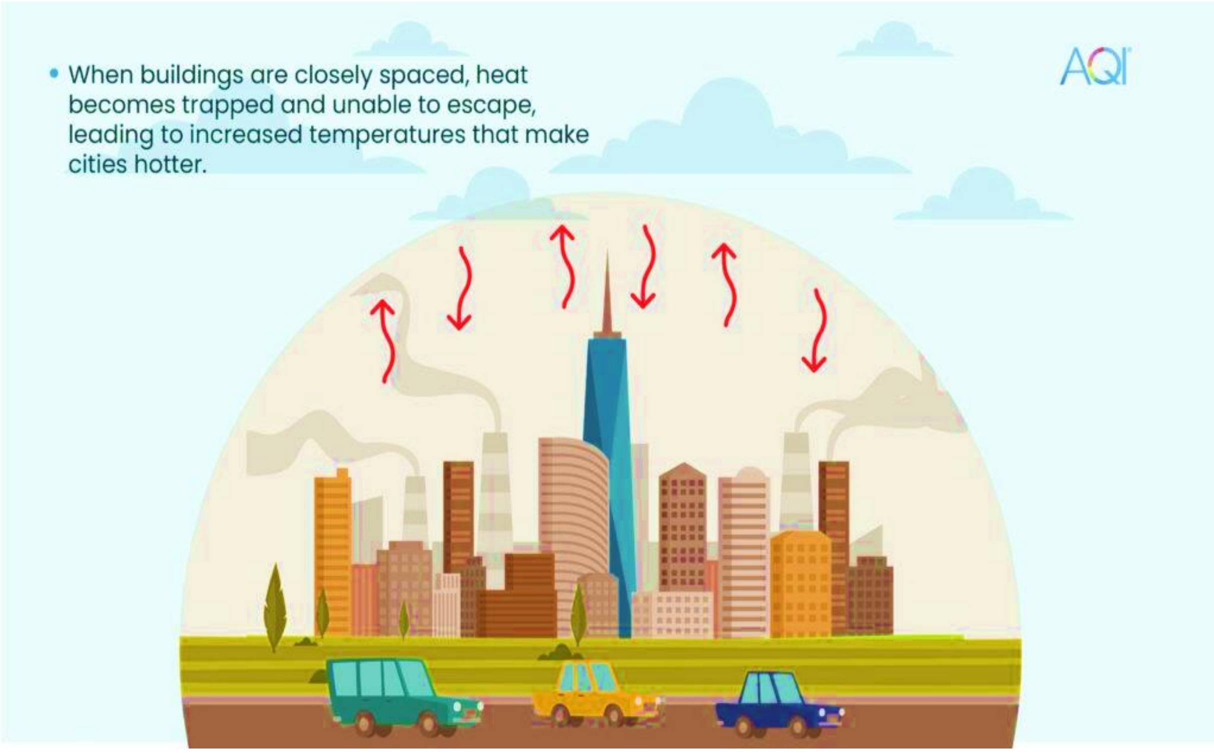


Figure 2: Urban Heat Trap (Source: AQI)

The consequences of UHIs extend beyond mere temperature increases; they impact communities by raising summertime peak energy demand, escalating air conditioning costs, increasing air pollution and greenhouse gas emissions, and heightening health risks such as heat-related illnesses and mortality. UHI also affects water quality as elevated temperatures alter the thermal balance in local bodies of water. The IPCC (Climate Change 2022 - Impacts, Adaptation, and Vulnerability) describes UHI as "the relative warmth of a city compared with surrounding rural areas," a difference that results from urban land use, built environment configurations, such as street layouts and building sizes, and the heat absorbing properties of urban materials. Limited ventilation, reduced green spaces, and heat generated directly from human activities, such as industrial and domestic sources, further contribute to this relative warmth.

Weather conditions and local meteorology, which include unique urban climates, significantly influence energy use patterns at the regional and local levels. UHI, a central feature of urban climates, has direct implications for energy consumption. During periods of high UHI intensity, air temperatures within a city can be several degrees higher than in surrounding rural areas, leading to a surge in peak electricity demand for cooling during summer months. Studies, such as those by Haider Taha ("Heat Islands and Energy"), indicate that peak electric demand in urban areas may increase by up to 10% due to the UHI effect.

UHI intensity is usually measured by comparing urban temperatures with those in nearby rural areas. However, temperatures can also vary within a city itself, leading to "intra-urban heat islands". Intra-urban heat islands arise from the uneven distribution of heat-absorbing materials, such as buildings and pavements, juxtaposed with cooler areas that feature trees, water bodies, or parks. Diagrams illustrating the UHI effect show that urban parks, ponds, and residential areas are often cooler than more densely built downtown zones, where concrete and asphalt dominate.

In understanding UHIs, it is essential to distinguish between surface heat islands and atmospheric heat islands. These differ in their formation mechanisms, measurement techniques, and impacts, as well as in cooling strategies:

- **Surface Heat Islands**: This occurs due to the heat-absorbing properties of urban surfaces such as roads and rooftops, which absorb and emit heat more than natural landscapes. During warm days, urban surface temperatures can far exceed air temperatures, sometimes by as much as 60°F. Surface heat islands are typically most intense during daylight hours, as materials like asphalt and roofing absorb significant solar radiation.

- **Atmospheric Heat Islands**: These occur when the air over urban areas is warmer than the air over adjacent rural zones. Atmospheric heat islands are generally less intense than surface heat islands and exhibit smaller temperature variations. They are most noticeable at night when the stored heat from urban surfaces slowly releases into the atmosphere, keeping urban air temperatures elevated.

This scientific distinction between surface and atmospheric heat islands provides insight into how the UHI effect operates across different urban contexts, affecting energy demand, air quality, and public health. Addressing UHI requires tailored strategies that consider the distinct characteristics of surface and atmospheric heat islands, as well as the unique urban fabrics of cities like Chennai, Coimbatore, and Madurai, to create sustainable and resilient urban environments.

Global Scenario

- In 2020, Houston collaborated with multiple agencies for a heat mapping project, revealing a significant 17+ degree gap between the hottest and coolest spots in Houston and Harris County.

- A study conducted in New York compared temperatures in the South Bronx to Central Park, revealing a striking 20-degree difference during the day and an even greater 22-degree difference at night.

WHY DO WE CARE ABOUT URBAN HEAT ISLANDS?

Elevated temperatures caused by urban heat islands (UHIs) can significantly impact a community's environment and quality of life. While UHIs may extend the growing season for plants, their adverse effects include increased energy consumption, higher emissions of pollutants and greenhouse gases, threats to human health and comfort, and degraded water quality. These negative impacts underscore the need for effective UHI mitigation strategies.

ENERGY CONSUMPTION

Urban heat islands raise summertime temperatures in cities, increasing demand for cooling and placing stress on the power grid, especially during peak periods on

URBAN HEAT ISLAND, CLIMATE CHANGE & GLOBAL WARMING

Urban Heat Islands (UHI): Urban heat islands refer to elevated temperatures in developed areas compared to surrounding rural areas, caused by infrastructure, altered surfaces, and the density of buildings. Features like tall buildings trap heat and slow night-time cooling. UHI intensity varies with location and weather patterns, affecting temperatures on a local scale and diminishing with distance from urban centres. UHIs are examples of localized climate change, limited in reach and primarily impacting city environments.

Climate Change: Climate change describes any significant and long-lasting alteration in temperature, precipitation, wind, or other climate factors, spanning decades or longer. Climate change can result from natural processes (like solar radiation changes or ocean currents) or human activities (such as deforestation or fossil fuel burning), affecting the atmosphere's composition and Earth's temperature over large regions or globally. While often used interchangeably with global warming, climate change encompasses broader phenomena, including changes in precipitation patterns, extreme weather, and sea level rise.

Global Warming: Global warming refers specifically to the average increase in Earth's surface temperature, primarily due to greenhouse gas emissions from human activities. This warming amplifies global climate change by altering climate patterns worldwide, increasing sea levels, and intensifying extreme weather events. Global warming is a component of climate change and is typically associated with the broader shifts that impact global ecosystems, agricultural cycles, and human health.

While urban heat islands are localized and mainly affect city temperatures, climate change and global warming operate on a global scale, driven by systemic changes in the climate. Both UHIs and global warming contribute to increased energy demands and associated pollution, particularly during hot seasons. Mitigating UHIs through green infrastructure and reflective surfaces helps reduce local temperatures and indirectly supports efforts to address global warming and climate change by lowering greenhouse gas emissions and improving air quality.

hot summer afternoons. For every 1°F (0.6°C) rise in temperature, urban electric demand can increase by 1.5 to 2 percent, meaning that up to 10 percent of a city's electricity usage can be attributed to the UHI effect. During extreme heat events, these increased demands may overwhelm the system, potentially leading to rolling blackouts or power outages.

AIR QUALITY AND GREENHOUSE GASES

The elevated temperatures from UHIs contribute to increased energy demand, which often leads to higher emissions of pollutants and greenhouse gases, particularly from fossil fuel power plants. Pollutants like sulphur dioxide, nitrogen oxides, and particulate matter degrade air quality, while greenhouse gases like carbon dioxide contribute to climate change. Additionally, elevated temperatures accelerate ground-level ozone formation, as nitrogen oxides and volatile organic compounds react more quickly in sunlight, further degrading air quality.

HUMAN HEALTH AND COMFORT

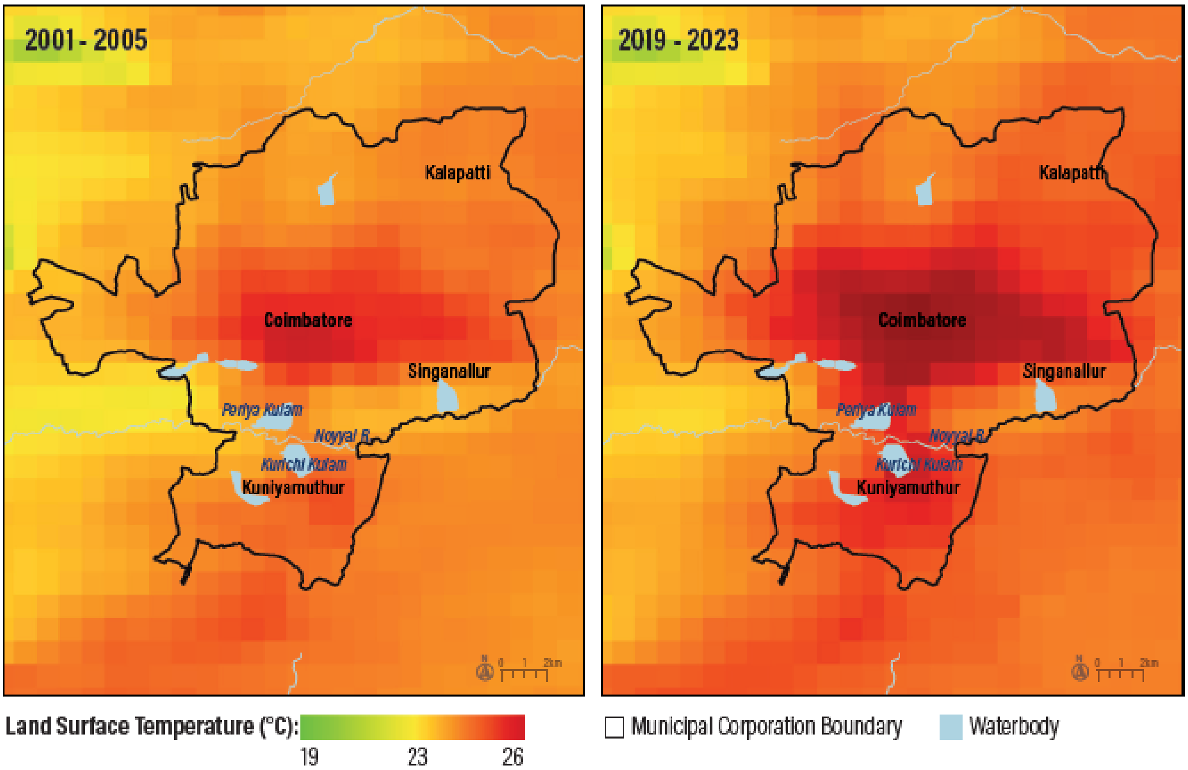
UHIs can negatively impact human health by increasing daytime temperatures, reducing night-time cooling, and elevating air pollution levels. These factors can lead to respiratory problems, heat-related illnesses, and even heat-induced mortality, especially during prolonged heat waves. Vulnerable groups, such as the elderly, children, and people with health conditions, are particularly at risk.

1.2 HEAT HAZARD AND VULNERABILITY IN TAMIL NADU

Tamil Nadu, India's southernmost state, experiences a semi-arid to sub-humid climate that exposes it to significant heat stress risks, particularly in the interior regions such as Tiruchirappalli, Tiruvannamalai, Kanchipuram, and Erode. While temperatures fluctuate between 18°C and 45°C annually, certain areas endure higher-than-average temperatures due to their inland locations and limited coastal influence. Tamil Nadu's diverse geography includes over 1,076 km of coastline, the Western Ghats, forests covering 20% of its area, and fertile plains, which create varied microclimates across the state. From 1989 to 2018, annual rainfall averaged 898 mm, with nearly half provided by the Northeast monsoon. As temperatures rise, the State is increasingly vulnerable to heat waves that threaten ecosystems and the health of its population.

TEMPERATURE TRENDS

Analysis of Tamil Nadu's climate data reveals significant warming trends. Since 1981, average maximum summer temperatures have risen by 1.5°C, with recent records showing an average summer high of 35.5°C. This increase affects 50% of the State's population, while around 15% experience a surge of 2°C in districts like Tiruchirappalli, Tiruvannamalai, and Vellore. Minimum temperatures have also risen, with an increase of 0.75°C across the State, indicating warmer nights that intensify discomfort and health risks. This warming pattern has led to an increased frequency of "disastrous heat wave days," which are defined by days with at least one heat-related fatality.



Source: :Nighttime Land surface temperature is based on MODIS Terra Land Surface Temperature and Emissivity Daily Global 1 km.

Figure 3: Night-time Land Surface Temperature patterns across Coimbatore

THERMAL COMFORT AND PROJECTED HEAT RISKS

With climate change projections indicating further temperature increases, Tamil Nadu is likely to face longer and more intense periods of heat discomfort. Research by Anna University's Centre for Climate Change and Disaster Management forecasts a rise in "thermal discomfort" days, expected to grow from 107 days annually (observed between 1985 and 2014) to 150 days per year by 2050. This increase in discomfort days will significantly impact public health, productivity, and ecological balance. The IMD has also recorded rising Heat Index levels during summer and monsoon seasons, indicating heightened thermal discomfort driven by increased humidity and air temperatures. Urbanized regions with limited vegetation and high density of built environments are most at risk, as they experience compounded effects from UHI. To manage these risks, there is a need for tailored heat mitigation strategies in Tamil Nadu that address both immediate and long-term challenges.

FUTURE HEAT RISK

Projections for air temperature in Tamil Nadu up to 2095, based on the Representative Concentration Pathway (RCP) 4.5 scenario, indicate a significant rise in temperature levels.

Analysis using 21 models from NEX GDDP (CMIP5) predicts an increase in maximum air temperature by 0.5-1°C by 2040, reaching up to 2°C above the baseline average (1975-2005) by 2095. By mid-century, approximately 71% of the population is projected to be exposed to above-average maximum temperatures, climbing to 80% by 2095.

Similarly, minimum temperatures are expected to rise by more than 1°C by 2040 and exceed 1.5°C by 2095. These projections underscore the urgent need for comprehensive strategies to mitigate the adverse effects of rising temperatures on public health and vulnerable communities.

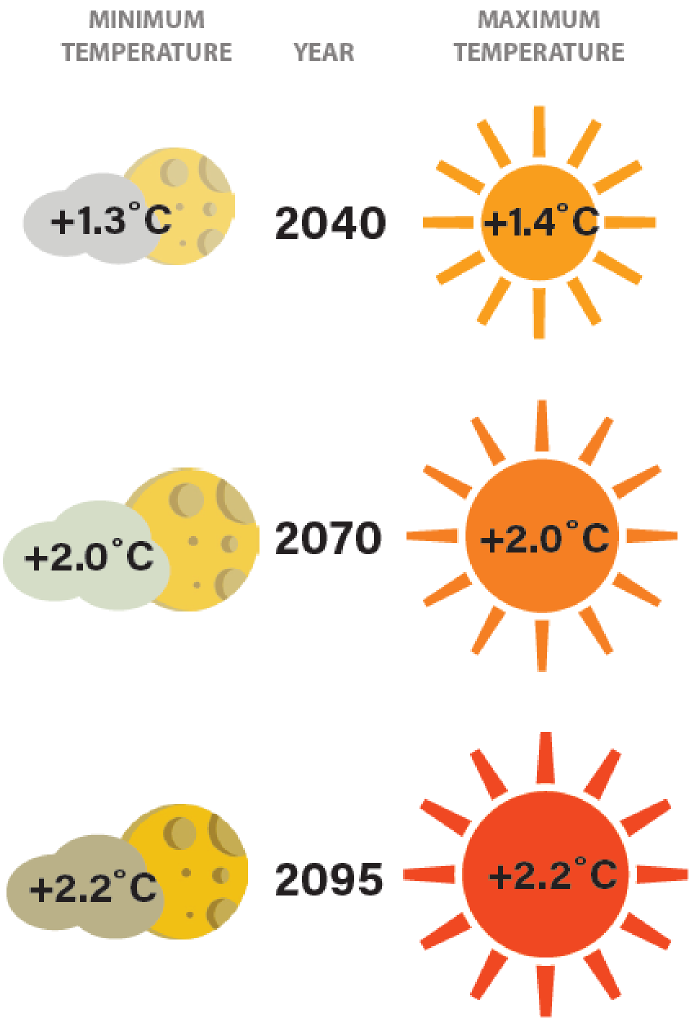


Figure 4: Temperature increase forecast for Tamil Nadu, with reference to the baseline period of 1975 – 2005

VULNERABILITY TO HEAT

Heat vulnerability in Tamil Nadu encompasses multiple dimensions, affecting human health, socio-ecological systems, buildings, animals, forests, agriculture, and environmental stability. Human vulnerability extends beyond physiological impacts and includes socio-economic factors like income, access to healthcare, and housing quality. Vulnerable groups, including the elderly, children, and individuals with pre-existing health conditions, are at heightened risk of heat-related illness and mortality. Rising temperatures also threaten socio-ecological systems, leading to water scarcity, food insecurity, and ecosystem disruption, exacerbating vulnerabilities in both urban and rural areas.

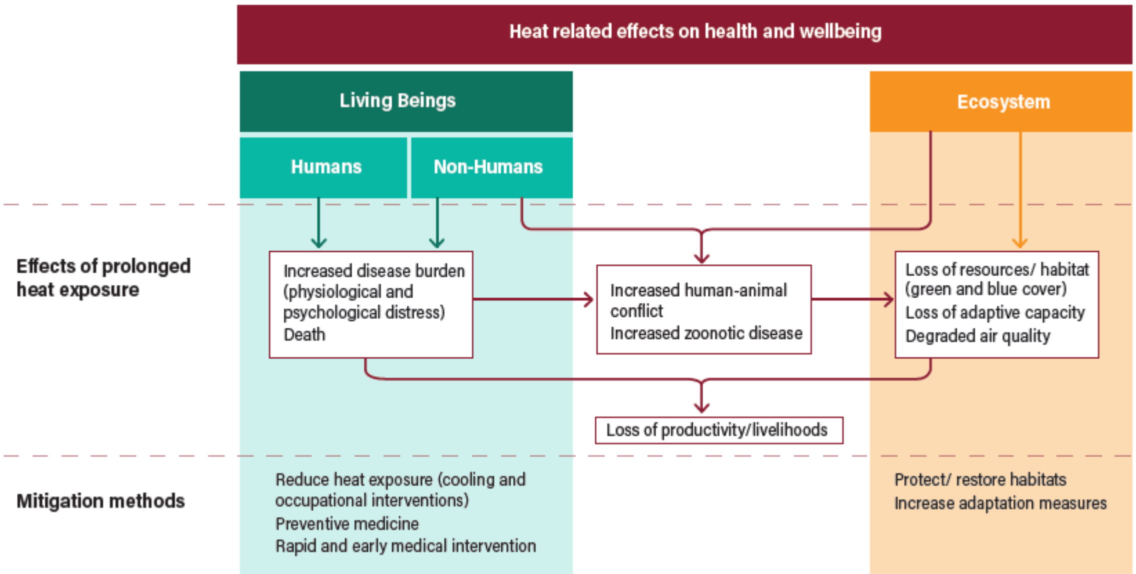


Figure 5: Interaction of extreme and prolonged heat with the health and well-being of humans, non-humans, and ecosystems

1.3 IMPACT OF HEAT ON PEOPLE, ECONOMY & ENVIRONMENT

Tamil Nadu's economy is India's second largest, generating around USD 266 billion in GSDP in 2020-21, with key contributions from automobile manufacturing, IT, textiles, and agriculture. However, climate and socio-economic challenges threaten this economic vitality, especially in urban areas where 48% of the population resides and nearly 35% live in slums, heightening vulnerability to heat stress. The State is highly susceptible to climate-related disasters, including cyclones, droughts, and floods, and incurs catastrophic economic losses of approximately USD 300-500 million per climate disaster. Out of Tamil Nadu's 38 districts, nine face drought risks, 10 are prone to flooding, and 17 are susceptible to heat waves. The frequency of forest fires has also surged, with 11% of the forested area at risk, impacting biodiversity, carbon sequestration, and resource availability in rural and urban landscapes alike. This comprehensive strategy identifies three systems affected by heat:

1. Natural Systems and Resources,
2. Vulnerable Livelihoods and Communities, and
3. Built Environments.

These systems were identified as focal points for identifying issues and the strategy recommends targeted actions. Through focused discussions, the State Planning Commission convened the Heat Action Network to enhance inter-departmental and inter-sectoral collaboration, facilitating convergence across policies and interventions to achieve a coordinated response to heat risks.

a. NATURAL SYSTEMS AND RESOURCES

This category includes critical ecological and rural-urban landscapes such as forests, agriculture, water resources, and animal ecosystems. These natural systems are essential for ecological balance and the health of human populations, underpinning sustainable and resilient communities. Heat waves exacerbated by climate change intensify droughts and disrupt habitats, impacting forest health, water resources, soil quality, and agricultural productivity. Frequent heat stress affects water availability, soil health, and the food-water-energy nexus, with further risks posed to energy generation and air quality.

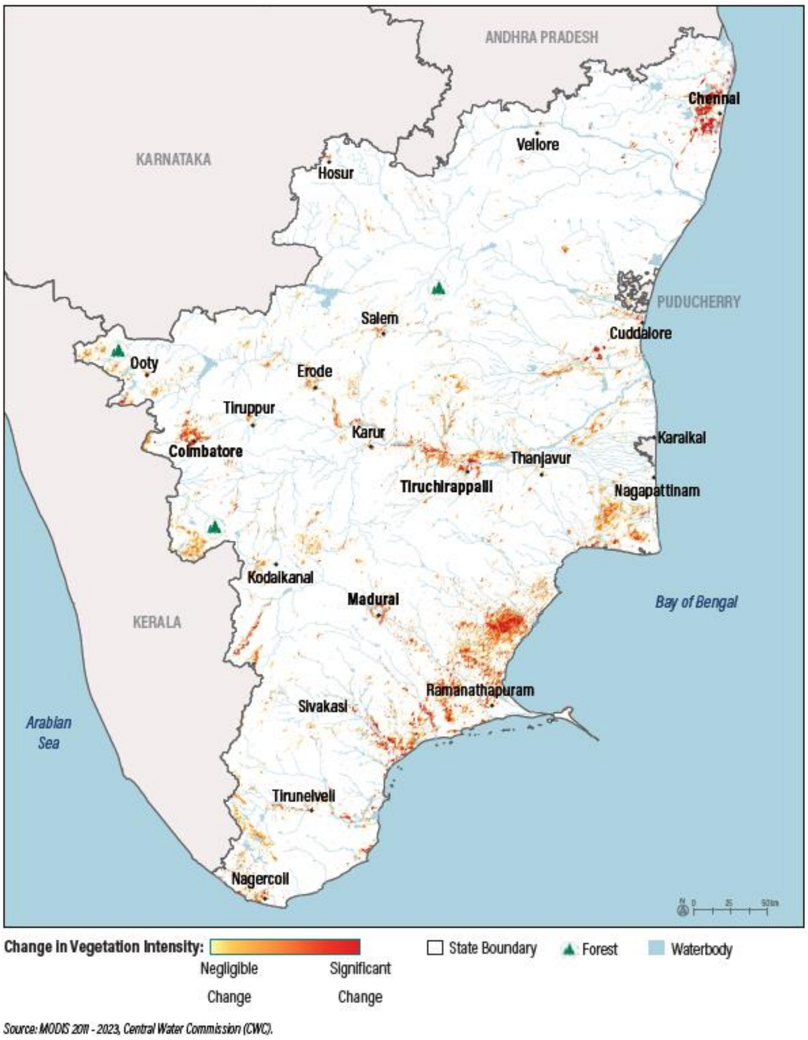


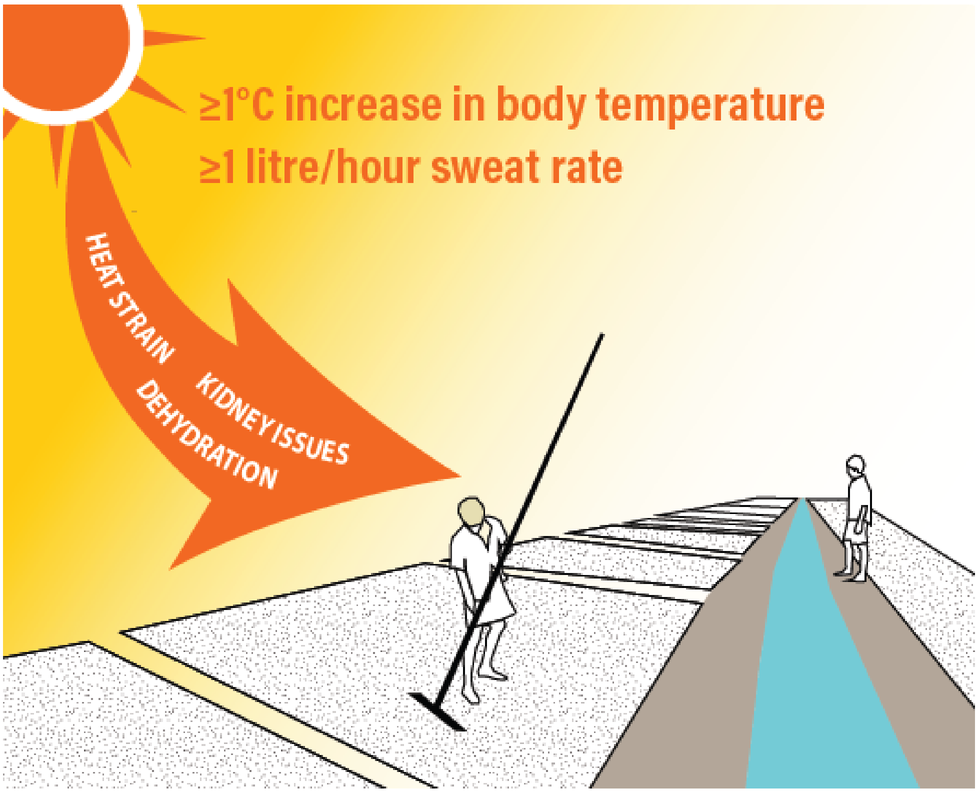
Figure 6 : Vegetation change in Tamil Nadu (2001 - 2023)

b. BUILT ENVIRONMENT

The built environment encompasses all human-made structures and surrounding environments, including buildings, physical and social infrastructure, and service delivery systems. These systems are increasingly vulnerable to heat stress, which degrades infrastructure resilience and service efficacy. Excessive heat exposure challenges energy demands for cooling and stresses existing infrastructure, amplifying risks for urban areas and the people who live and work within them. The built environment plays a dual role in either protecting people from or exacerbating heat stress. Poorly designed buildings, inadequate ventilation, and inappropriate materials contribute to thermal discomfort, especially in public spaces like hospitals, schools, markets, and administrative buildings. Infrastructure sectors, including food supply, transport, water distribution, and waste management, are also strained by rising temperatures. As heat intensifies, the demand for critical services grows, increasing operational and maintenance costs and putting further pressure on social and civic infrastructure.

c. VULNERABLE LIVELIHOODS AND COMMUNITIES

This system focuses on population groups disproportionately affected by heat due to socioeconomic, health or environmental factors. Vulnerable groups include children, the elderly, outdoor workers, and those in heat-sensitive jobs with limited access to resources. Heat exposure exacerbates the risks for people working in agriculture, construction, and other outdoor sectors, impacting health, productivity, and livelihoods. Heat stress also affects animal husbandry and agriculture, altering animal behaviours, reducing crop yields, and degrading the nutritional value of food, ultimately threatening both livelihoods and food security.



Source: Representation of Heat related illnesses prevalent among salt pan workers; adapted from Occupational Heat Stress and Kidney Health in Salt Pan Workers (Venugopal, et al., 2023).

Figure 7: Rising heat stress poses grave occupational health risk to the salt pan workers in Tamil Nadu

Livelihoods reliant on climate-sensitive sectors, such as agriculture, animal husbandry, fisheries, and tourism, are particularly vulnerable to extreme heat. Rising temperatures alter ecological systems, leading to water scarcity and other resource challenges that directly impact productivity and economic returns. Rain-fed agriculture, small-scale fishing, and animal husbandry are heavily affected by reduced yields and worker productivity losses, while the tourism sector suffers from decreased demand and operational limitations during heat wave alerts. Workers in adverse conditions—such as outdoor labourers, informal workers, and those exposed to intense mechanical or indoor heat—face significant health risks. High heat levels undermine labour productivity, with workers in roles that require extended periods outdoors or in hot environments, such as furnace and incinerator operations, being especially susceptible. This leads to reduced work output, increased fatigue, and higher absenteeism, resulting in economic setbacks and challenges in maintaining a productive workforce.

Certain population groups face heightened risks from heat stress due to limited access to critical infrastructure and services. Factors such as poverty, social marginalization, and inadequate living conditions intersect, making it harder for these groups to respond effectively to rising temperatures. Vulnerability varies widely depending on individual and community contexts, with complex social, environmental, and political factors amplifying their susceptibility to heat stress.

CHALLENGES IN RECORDING HEAT IMPACTS

Heat-related deaths and illnesses are significantly underreported across India due to limited protocols and awareness around heat hazards. Institutions such as the India Meteorological Department (IMD) and National Disaster Management Authority (NDMA) recommend that state-level committees monitor and report heat-related casualties accurately. Guidelines suggest that each district records maximum temperatures, conducts autopsies when needed, and provides evidence for deaths attributed to heat exposure. Yet, reporting remains inconsistent, with only about 10% of total heat-related deaths officially documented. This discrepancy arises due to inadequate awareness among healthcare professionals and gaps in resources across health institutions, especially in rural areas. Moreover, heat is not yet classified as a disaster under India's National Disaster Management Act of 2005, limiting funds for heat mitigation to a fraction of the State Disaster Response Fund (SDRF). Without an official classification, the state's heat preparedness relies on local actions without comprehensive federal support for heat-related interventions.

a. Built Environment and Ecological Systems

Buildings not designed for extreme heat, lacking proper ventilation, insulation, and cooling systems, contribute to indoor heat stress, affecting the well-being and productivity of occupants. Ecosystems also face significant risks: animals and forests are impacted by habitat loss, biodiversity decline, and ecosystem degradation. This, in turn, disrupts ecological balances and services essential to sustaining life. Agriculture is particularly susceptible, as crop failures, livestock losses, and reduced yields become more common due to heat stress, drought, and increased pest outbreaks, threatening food security across the region.

b. Conceptualizing Heat Vulnerability and Policy Implications

Addressing vulnerability to heat requires interdisciplinary research, stakeholder engagement, and proactive policy interventions that target both human and natural systems. Government agencies, in collaboration with experts, should conduct detailed baseline assessments for vulnerable groups and sectors. A thorough needs assessment will provide a foundation for targeted strategies that enhance resilience, ensuring the well-being of communities and sustainable management of natural resources amidst rising temperatures.

1.4 HEAT MITIGATION STRATEGY FOR TAMIL NADU

The Heat Mitigation Strategy for Tamil Nadu focuses on addressing the unique challenges posed by heat exposure, which affects various groups differently. Children, seniors, pregnant women, persons with disabilities, outdoor workers, and migrant labourers are especially vulnerable. Excessive heat exposure impacts not only human health and productivity but also affects ecological and economic systems, which can contribute to shifting climate patterns. Current Heat Action Plans in India emphasize response and recovery, with limited focus on long-term heat mitigation. Acknowledging these gaps, the Tamil Nadu State Planning Commission, with support from the British High Commission, has developed a strategy that prioritizes a multidisciplinary approach to heat mitigation. This strategy seeks to address the urgent need for heat resilience, especially in developing regions with limited resources. The HMS focus is on three goals:

1. Improving human well-being,
2. Protecting ecosystems, and
3. Tackling climate change.

By fostering interdepartmental collaboration, aligning policies, and identifying areas of convergence, the HMS provides a structured approach to mitigate extreme heat effects, thus safeguarding public health, food security, and sustainable development in Tamil Nadu.

The development of Tamil Nadu Heat Mitigation Strategy (TN HMS) involved extensive consultations with experts in meteorology, ecology, disaster risk management, data analytics, and urban planning, among others. This collaborative effort brought together scientific and local insights, addressing social, cultural, and economic factors specific to Tamil Nadu. The report provides baseline data on heat stress indicators and spatial and temporal variations in heat exposure, supporting the State's ongoing efforts to build heat resilience and guide policy planning and implementation. Recommendations within the strategy are categorized into short-term and long-term actions, organized across three action pathways outlined below. Chapter 4 details the recommendations under each of these pathways.

HEALTH AND WELLBEING

This area addresses the physical, mental, and social health of human populations, along with the ecological health of animals, marine life, and plants. It focuses on ensuring resilience to heat stress for all living organisms and their environments, promoting a balanced ecosystem that can withstand rising temperatures.

SUSTAINED RESOURCES AND ECONOMIC PRODUCTIVITY

This action area prioritizes the sustainable use and availability of essential natural resources, such as water, clean air, and energy, to support economic activities. It aims to sustain agricultural productivity, industrial output, human and animal labour, and infrastructure resilience without depleting or damaging the environment. The goal is to balance resource consumption with conservation efforts, fostering long-term ecological and economic stability amid increasing heat stress and climate change.

COOLING SOLUTIONS

Cooling solutions encompass strategies and technologies designed to minimize heat exposure for individuals, built environments, and ecosystems. This includes systemic design, development, and urban planning measures alongside innovative technologies to enhance thermal comfort and reduce the impact of heat stress on all.

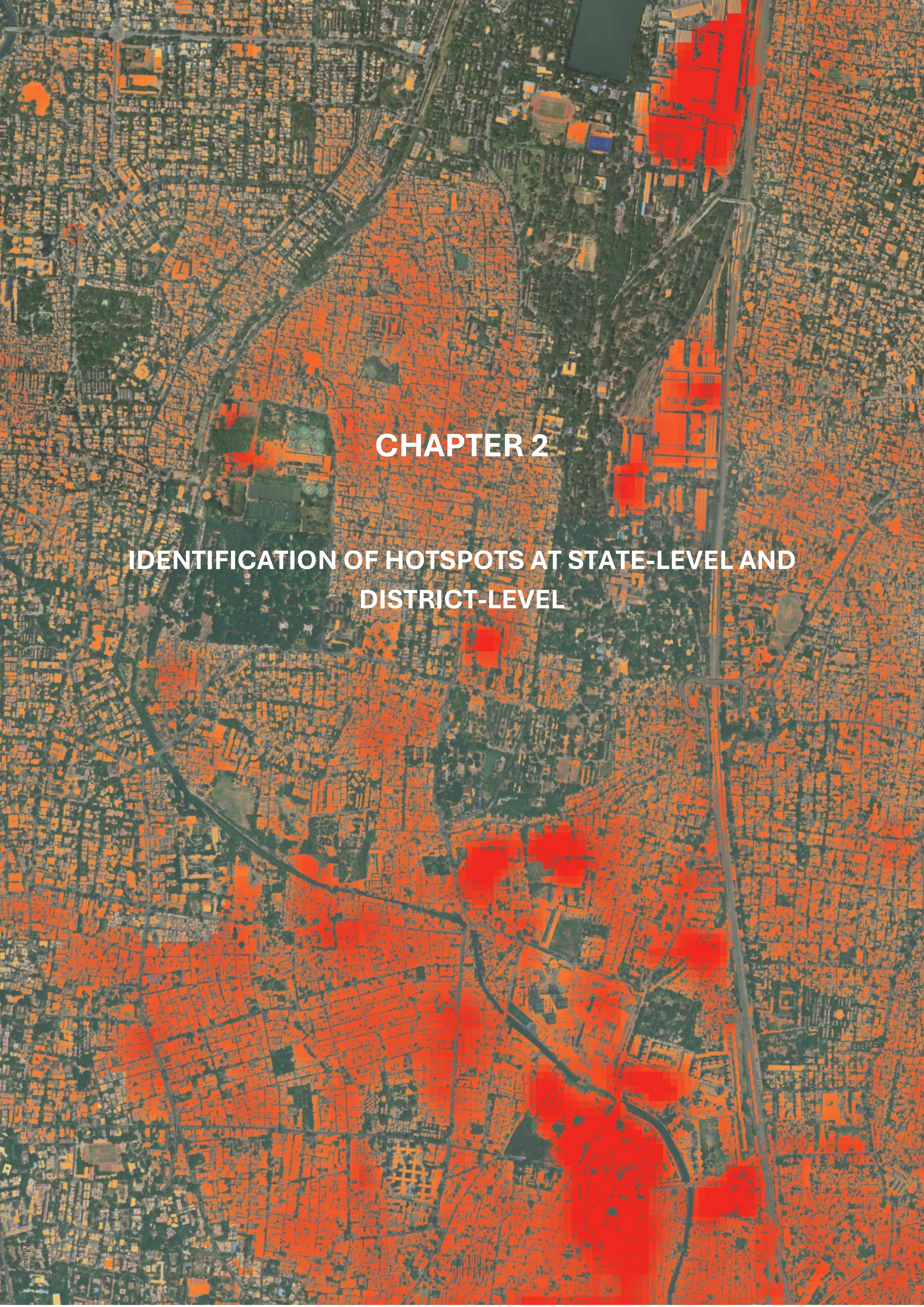
The report emphasizes integrating these measures at scale to minimize heat impacts State-wide, supported by a cross-functional, inclusive approach to build sustainable heat resilience for Tamil Nadu. The goal of the heat mitigation strategy document is to outline measures and mechanisms to reduce heat stress and safeguard ecosystem health. This strategy, informed by multi-sectoral assessments and insights from consultations, aims to improve the adaptive capacity of vulnerable groups while ensuring their productivity despite rising temperatures.

The strategy promotes comprehensive, scalable recommendations across three action pathways listed above. Integrating these areas allows for policy coherence, enabling interventions with multiplier effects and co-benefits. Tamil Nadu faces the dual challenge of safeguarding ecosystems while addressing economic inequalities, worsened by limited access to essential services. By focusing on equitable access to resources, the strategy seeks to foster a healthier, more resilient, and stable environment for all residents, setting the foundation for a sustainable future in a warming climate. The three action pathways highlighted in the HMS gets justified with the findings of the recently published Lancet report on Health and Climate Change in October 2024. The report reveals the escalating human impact of climate change, particularly from rising temperatures. Between 2019 and 2023, people worldwide faced an average of 46 extra days of health-threatening heat, reaching 50 additional days in 2023, with 31 countries experiencing at least 100 more heat-dangerous days than expected without climate change. This heat exposure was notably higher in countries with lower Human Development Index scores, underscoring global inequalities in climate vulnerability. India, especially, experienced record-breaking heatwaves, with each person exposed to over 2,400 hours (approximately 100 days) of moderate heat stress, making even light outdoor activities risky.

The report further highlights the widespread disruption of sleep, with high temperatures leading to a 6% increase in sleep loss compared to 1986-2005 levels, which affects both mental and physical health. Climate impacts also extended to food security, as by 2022, 151 million people across 124 countries faced moderate to severe food shortages from heatwaves, droughts, and extreme weather. Vulnerable groups, like infants and the elderly, were severely affected, with each exposed to 7.7 and 8.4 heatwave days per year, respectively, from 2014-2023, marking significant increases over previous decades. Economic consequences were stark, as heat exposure led to the loss of 181 billion potential labour hours globally in 2023, translating to an estimated $141 billion in lost income due to reduced labour capacity.

CHAPTER 2

IDENTIFICATION OF HOTSPOTS AT STATE-LEVEL AND DISTRICT-LEVEL



SYNOPSIS

This chapter presents a study of 'State-level and District level heat map and identification of hotspots in Tamil Nadu' which was commissioned by Tamil Nadu State Land Use Research Board with the support from UNEP. CEPT University conducted this assessment with the aim to provide State-level heat mitigation recommendations by developing a state-level heat map, dividing the state into heat zones at the district level, and identifying hotspots for the State Government's comprehension and for integration into future land use planning. The methodology outlines an assessment of Surface Urban Heat Island (SUHI) trends across the state of daytime and night-time, at the state and district level of Tamil Nadu for the past two decades (2003-2023). Additionally, the district-level heat zones and UHI intensity were determined to comprehend the impact of climate change and urbanization on the temperature patterns.

Spatio-temporal analysis reveals that Tamil Nadu has witnessed notable changes in Land Surface Temperature (LST) across different seasons from 2003 to 2023. There has been a consistent increase in night-time LST, particularly in summer with a substantial increase in areas by 59% with a night-time LST between 24-26°C over the years. In contrast, there was a significant drop of areas experiencing intense heat, with a daytime LST between 46-50°C by 28.2% of the total state. Urban areas, under clear, calm sky conditions gradually release accumulated heat at night, causing the surface and ambient temperatures to rise. This increase often persists without cooling down significantly until the following day. Therefore, to verify seasonal night-time LST changes, night-time LST maps were derived. These night-time LST difference maps show how Urban Heat Island effects have increased across different seasons providing insights of how night-time LST has increased in different parts of the Tamil Nadu state with mean LST increasing by 1.5 °C across smart cities, emphasizing the need for targeted mitigation strategies against UHI effects.

To identify the hottest districts of Tamil Nadu over the two decades daytime and night-time mean LST data for four time periods were taken (2001-2003, 2011-2013, 2017-2020 and 2021-2023). To mitigate anomalies in an individual year data, average of three-year periods was computed providing a more stable representation of LST trends over time period. As per analysis, Thoothukkudi emerges as a district consistently experiencing maximum daytime mean LST reaching above 42°C in various periods, while Chennai experiences the highest night-time change in LST over the analysed period. Chennai's average night-time LST increased by 1.5°C from 23°C in 2001-2003 to 24.5°C in 2021-2023.

To analyse the behaviour of all districts across Tamil Nadu when hottest and coldest day and night were observed in the year 2023 air temperature data was collected from 61 weather stations across Tamil Nadu and identification of the hottest and coldest days and nights was done. Based on those dates, four months mean LST data was taken for all districts to see their temperatures on those days. During the hottest day in June, several districts recorded LST between 42°C to 44°C, indicating widespread heat across the state. Conversely, on the coldest day in December, certain districts, such as Chennai, Karur, and the central part of Tamil Nadu, still maintained relatively warm LST above 30°C. For night-time temperatures, the highest night-

time air temperature in August was observed, particularly in coastal regions such as Chennai, Thoothukkudi, and Cuddalore, where temperatures ranged from 25°C to 26°C. Conversely, during the coldest night in January, some districts like Chennai and Nagapattinam maintained temperatures above 24°C, suggesting relatively mild conditions even during colder months.

Finally, Urban Heat Island Intensity was determined to understand the impact of climate change and urbanization on the temperature patterns. Chennai district exhibited UHI intensity of about 2.5 °C, while other districts such as Madurai, Tiruvallur, Chengalpattu, Erode and Salem recorded values around 2°C. Whereas by 2023, there was an increase in UHI intensity, with Chennai, Thiruvallur and Ramanathapuram reaching values close to 3°C and districts like Madurai, Thoothukkudi and Virudhunagar experiencing intensities around 2.5°C. Regions having higher levels of urban development exhibited higher Urban Intensity values, indicating more heated temperatures in these densely built-up areas whereas areas with lower concentration of built-up shows relatively lower urban intensity values, displaying reduced heated temperatures in less urbanized areas. The insights can enable government stakeholders to take proactive measures and make informed decisions to address the growing challenges associated with Urban Heat Island Effect and rising temperatures, ultimately resulting in the development of healthier, more resilient, and sustainable cities.

2. IDENTIFICATION OF URBAN HEAT HOTSPOTS AT STATE-LEVEL AND DISTRICT-LEVEL

In recent decades, there have been significant shifts in the distribution of maximum and minimum temperatures recorded across many regions worldwide, unmistakably indicating a trend toward warmer temperature regimes (Donat & Alexander, 2012). Episodic occurrences of extremely high surface air temperatures spanning multiple days across the Indian subcontinent have been on the rise during the last five decades (Rohini et al., 2016). Also, while both the daytime and night-time temperature extremes have been increasing, the warm spells in night-time temperatures have surged more rapidly than daytime temperatures (Mishra et al., 2017).

India has become a hotspot for heat-related mortality. An increasing toll of deaths due to heat waves recorded a spur in recent decades from a cumulative of 5,330 deaths reported during 1978–1999 to extreme cases of 3,054 and 2,248 deaths in 2003 and 2015, respectively (Chaudhury et al., 2000; Ratnam et al., 2016). Heat-wave-related mass mortality events in India are expected to increase from 46 to 82%, with the shift in the mean number of heat-wave days from 6 to 8 (Mazdiyasni et al., 2017).

The climatic conditions in Tamil Nadu, situated in south-eastern India, have gradually shifted, transforming the state from a dry sub-humid region to a semi-arid one in recent years. (Raju et al., 2013). Particular findings indicate that by the end of the century, there may be an increase of 3.30 °C during the day and 3.55 °C during the night, and there would be a 3.24% drop in rainfall (TNGCC, 2022). People who live in these areas are negatively impacted by the severe temperatures and atmospheric conditions that follow since they can lead to physiological stress and occasionally even death (Ministry of Health and Family Welfare (Government of India), 2022).

Hence, documenting the current state of Tamil Nadu is imperative. This step will furnish a comprehensive understanding of the changes and reforms that have occurred over the years, along with identifying vulnerable areas that require attention. Such documentation is essential before delving into the complexities of the Urban Heat Island Effect (UHIE) and evaluating the continuous efforts aimed at mitigating its impact.

CONTEXT

In this section, the present context of Tamil Nadu state has been discussed, taking inferences from master plan documents, census, public surveys, academic research, and policy documents to provide a brief overview before going into main content, which will be crucial considering the UHIE and its impacts.

A. DEMOGRAPHICS

Tamil Nadu, a state in India, has a population of approximately 7.21 crores. According to the detailed analysis of the Population Census 2011 published by the Government of India, the population of Tamil Nadu has grown by 15.61% in the last decade (2001-2011) compared to the previous decade (1991-2001) (*Population Census 2011 India*, 2011). The current decade witnesses a population density of 1437 per square mile in Tamil Nadu and is going to increase in the next decade. Hence, given the environmental risks posed by floods and urban heat stress, it's crucial to assess their influence on demographics to develop a comprehensive solution.

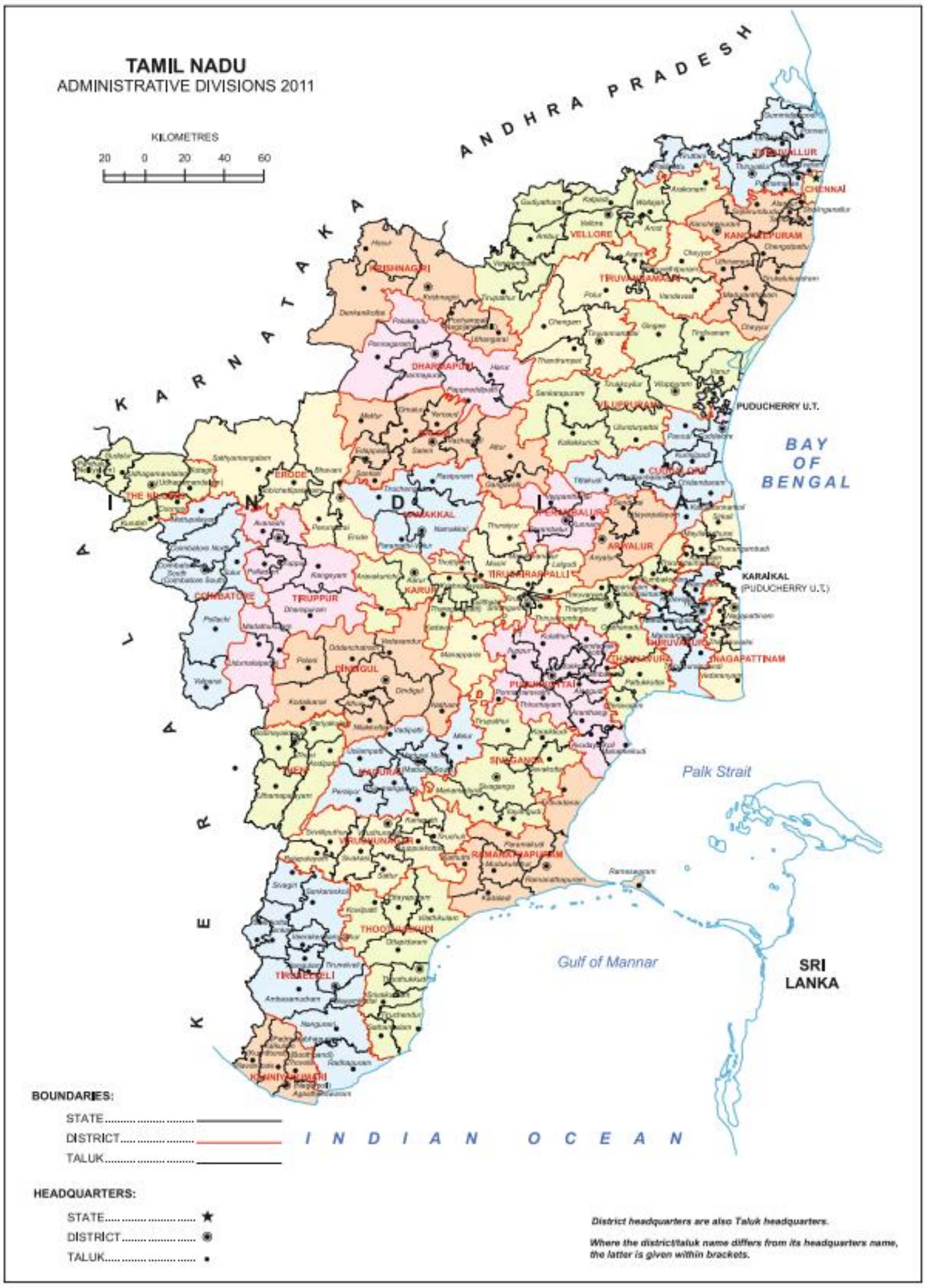


Figure 8: Administrative Division Map of Tamil Nadu (Census, 2011)

B. RISING TEMPERATURES AND HEAT STRESS

According to research conducted by Anna University's Centre for Climate Change and Disaster Management, the average number of days in 39 districts that are uncomfortable due to heat has increased by 41.5% since 2014. This trend is predicted to continue until 2050 (Padmaja J, 2024). As per scientific studies using the PRECIS regional climate model, there's an indication that the maximum temperature in Tamil Nadu could rise by approximately 3.1 °C. (TNGCC, 2022). As per monthly weather summary report for Tamil Nadu published by IMD, isolated pockets of North Interior Tamil Nadu experienced heat wave conditions on April 7th, 8th, 24th, 25th, and 26th, while interior Tamil Nadu faced similar conditions on April 9th and 20th, 2024. Throughout the month, maximum temperatures in subdivisions of Tamil Nadu were significantly higher than usual at certain locations (India Meteorological Department, 2024).

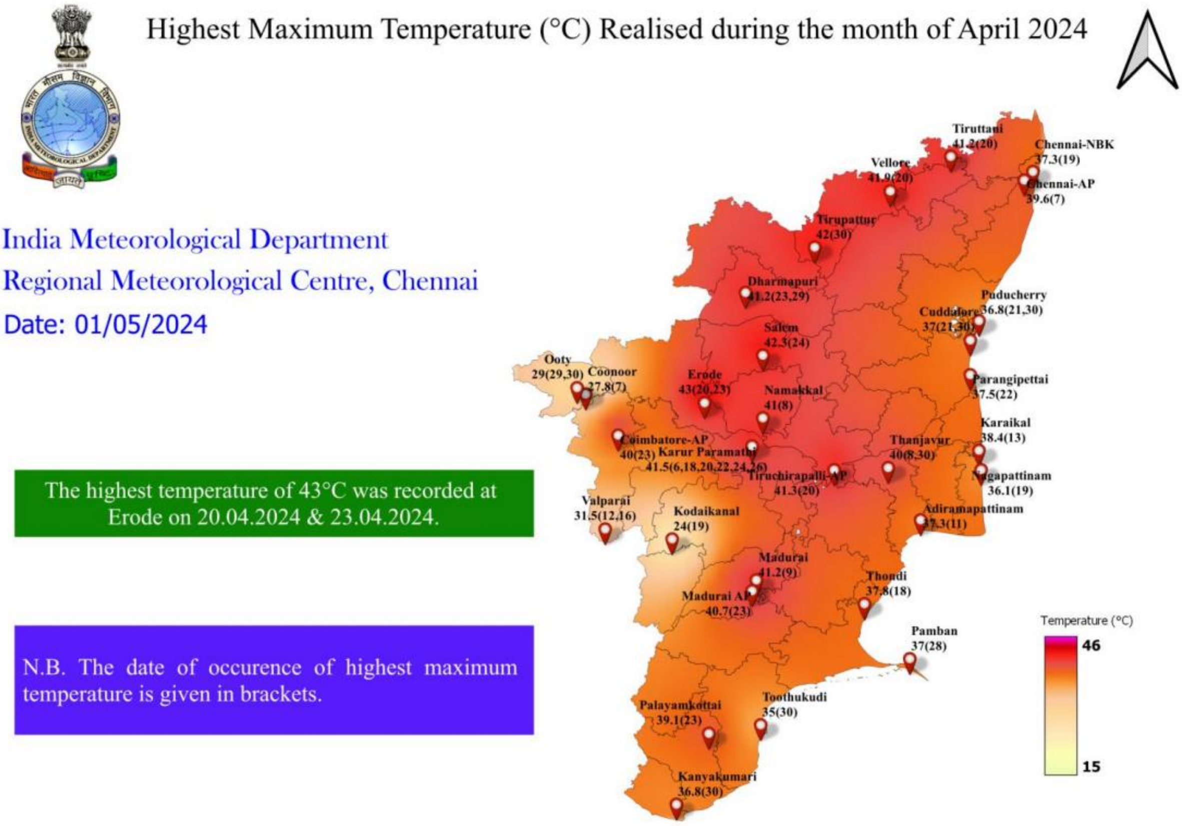


Figure 9 : Highest maximum temperatures recorded during April 2024 for Tamil Nadu (India Meteorological Department, 2024)

OBJECTIVE OF THE STUDY

The objective of this study is to provide state-level support for heat mitigation efforts in Tamil Nadu state by developing a state-level map, dividing the state into heat zones at the district level, and identifying hotspots for the State Government's comprehension and for integration into future land use planning.

2.1 APPROACH AND METHODOLOGY

The approach considered for data collection and mapping, analysis, and validation of the results will be discussed in this chapter. The methodology is developed to achieve the objective of preparing an evidence-based rationale for the Tamil Nadu state government to follow up with better decision-making concerning the mitigation of urban heat both at the state and the district level.

2.1.1 DATA COLLECTION

REMOTE SENSING DATA

The datasets from remote sensing will enable the acquisition of spatio-temporal changes in Land Use Land Cover (LULC) and Land Surface Temperature (LST) at a predefined resolution in a single snapshot.

Following remote sensing datasets were collected for this analysis:

i. Yearly Temporal data of MODIS (aqua and terra sensors) Land Surface Temperature retrieved at 1km pixels for the years spanning from 2003 to 2023 for daytime and night-time.
ii. Monthly Temporal data of MODIS (aqua and terra sensors) Land Surface Temperature retrieved at 1km pixels for the years spanning from 2003 to 2023 for daytime and night-time.
iii. Landsat8 (TIRS bands) satellite data having a spatial resolution of 30 meters for the year of 2013 and 2023.

SPATIAL ADMINISTRATIVE DATA

Spatial Administrative data refers to location-based data demarking any boundary or parcel at an administrative level. Following remote sensing datasets were collected for this analysis: -

i. Tamil Nadu State Boundary
ii. Tamil Nadu District Boundary

METROLOGICAL DATA

Metrological data refers to any data consisting of physical parameters like temperature, wind speed, wind direction, cloud cover, etc. which are measured by instruments. Air Temperature at daily intervals for 2023 from 61 weather stations of Tamil Nadu was used for this analysis.

2.1.2 METHODOLOGY

TREND ANALYSIS OF LAND SURFACE TEMPERATURE AT THE STATE LEVEL

For identifying spatio-temporal trends in Land Surface Temperature (LST) from 2003 to 2023 in Tamil Nadu, mean daytime and night-time LST data were obtained for the specified period along with the administrative boundary of the state. The data was then categorized into four seasons (Summer, Monsoon, Post Monsoon, and Winter). The LST data was extracted and clipped for the Tamil Nadu administrative boundary, and based on the mean LST values, the temperature range was defined and assigned to the data. Finally based on the obtained output, mean daytime and night-time seasonal LST maps were prepared for the years of 2003 to 2023. The methodology is illustrated in Figure-10.

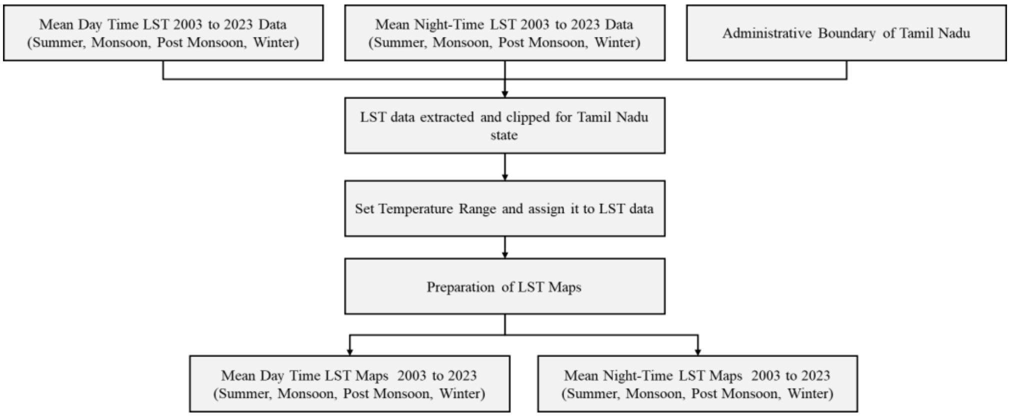


Figure 10: Methodology for trend Analysis of Land Surface Temperature between 2003 to 2023

SEASONAL NIGHT-TIME LST CHANGES BETWEEN 2003 AND 2023 AT THE STATE LEVEL

For identifying the night-time LST changes between 2003 and 2023, the seasonal night-time data for the years 2003 and 2023 was assessed. The spatio-temporal changes were calculated using the Raster Calculator, and a temperature range was assigned to the data. Finally, the LST maps for four seasons were developed, showing the spatio-temporal changes in LST over the two decades, emphasizing the various smart cities across Tamil Nadu state. The methodology is mentioned in Figure .

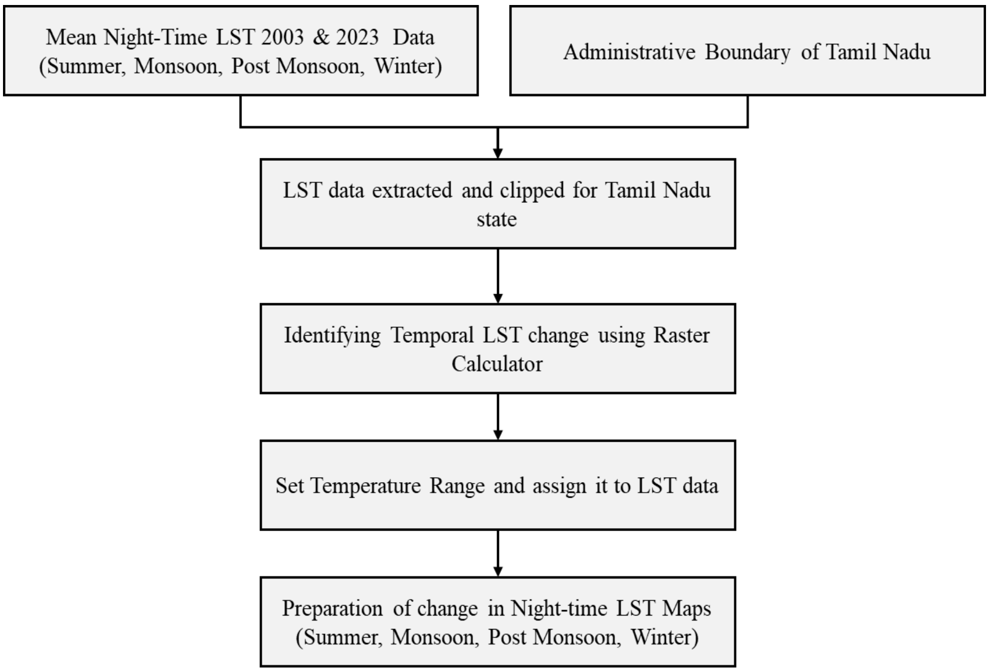


Figure 11. Methodology for assessing the changes in LST across four seasons between 2003 to 2023

IDENTIFICATION OF THE HOTTEST DISTRICTS OF TAMIL NADU

To develop the district-level heat zones, the hottest districts of the state have firstly been identified by considering three-year mean daytime and night-time LST data for four time periods.- i) from 2001 to2003, ii) from 2011 to 2013, iii) from 2017 to 2020, and iv) from 2021 to 2023, respectively.

Using the administrative boundary of the state, the LST data was clipped to focus only on the area of interest. Subsequently, empirical calculations, including minimum, maximum, and mean values, were calculated for each of the four time periods, and then the LST maps for daytime and night-time were prepared. The methodology is mentioned in Figure-12.

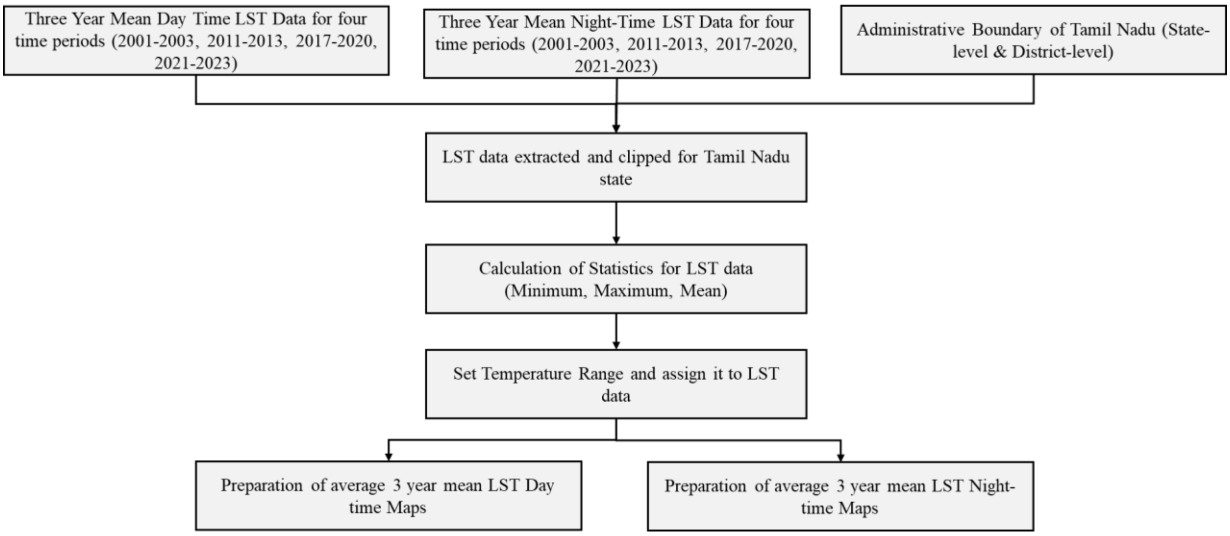


Figure 12: Methodology for identifying the hottest district of Tamil Nadu

ANALYSIS OF THE DAY AND NIGHT-TIME LST VARIANCE ON THE HOTTEST AND COLDEST DATES OF 2023

Once the hottest districts have been identified from the earlier assessment of the spatio-temporal behaviour of land surface temperature, the integration of air temperature with surface temperature has been aimed at, to strengthen the rationale for developing and validating the district-level heat zone

Therefore, to identify the four critical dates with the hottest day, hottest night, coldest day, and coldest night of 2023, air temperature data across the state were collected from 61 weather stations. Then daily mean air temperature for daytime and night-time were calculated for the acquired data. From the calculation, the months with the hottest and coldest days and nights of the year 2023 were determined. Then, the mean LST data for the identified four months based on the hottest and coldest days and nights were acquired. The Mean of LST was derived, and the temperature range was assigned against the day and night-time for assessment. The methodology for preparing the maps as a part of the district-level assessment of UHI is mentioned in Figure-13.

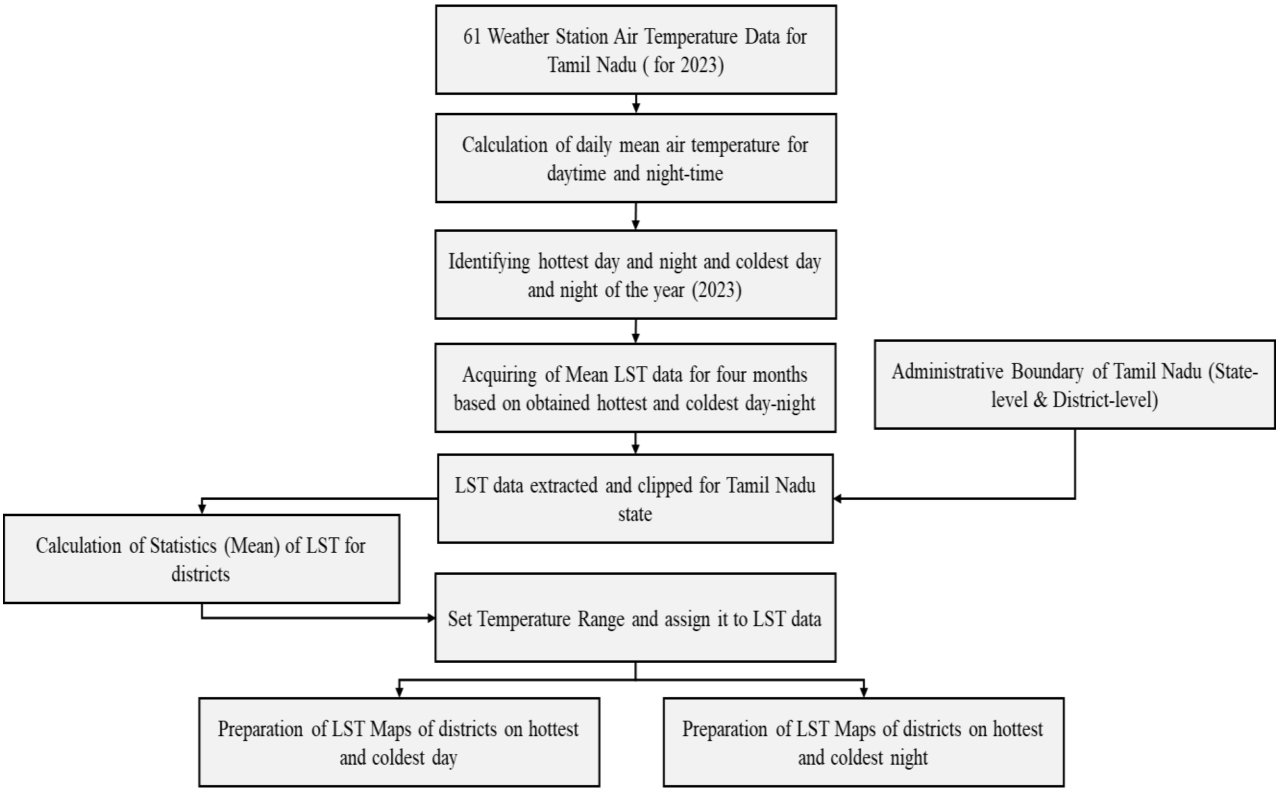


Figure 13 : Methodology for preparing the day and night-time LST maps on the hottest and coldest day of 2023

DERIVATION OF DISTRICT LEVEL HEAT ZONES FROM SURFACE UHI INTENSITY

To follow up with the conclusion from the earlier assessments, the objective of the assessment is to map the district-level heat zone with surface-level UHI intensity.

Therefore, Landsat 8 data for the years 2013 and 2023 was obtained, and images were classified into four classes, namely i) Built-up, ii) Open space/Barren land, iii) Vegetation, and iv) Waterbodies, from which LULC maps were prepared. Simultaneously, built-up areas were extracted from the classified image to emphasize the urban core. Summer night-time LST data was acquired for similar years, and LST for the built-up areas was extracted. The mean LST for the built-up areas was calculated and subtracted from the built-up LST data ((Built-up LST) – (Mean Built-up LST)) to calculate the UHI intensity. Temperature ranges were defined, and surface UHI intensity was mapped. The methodology flowchart is mentioned in Figure-14.

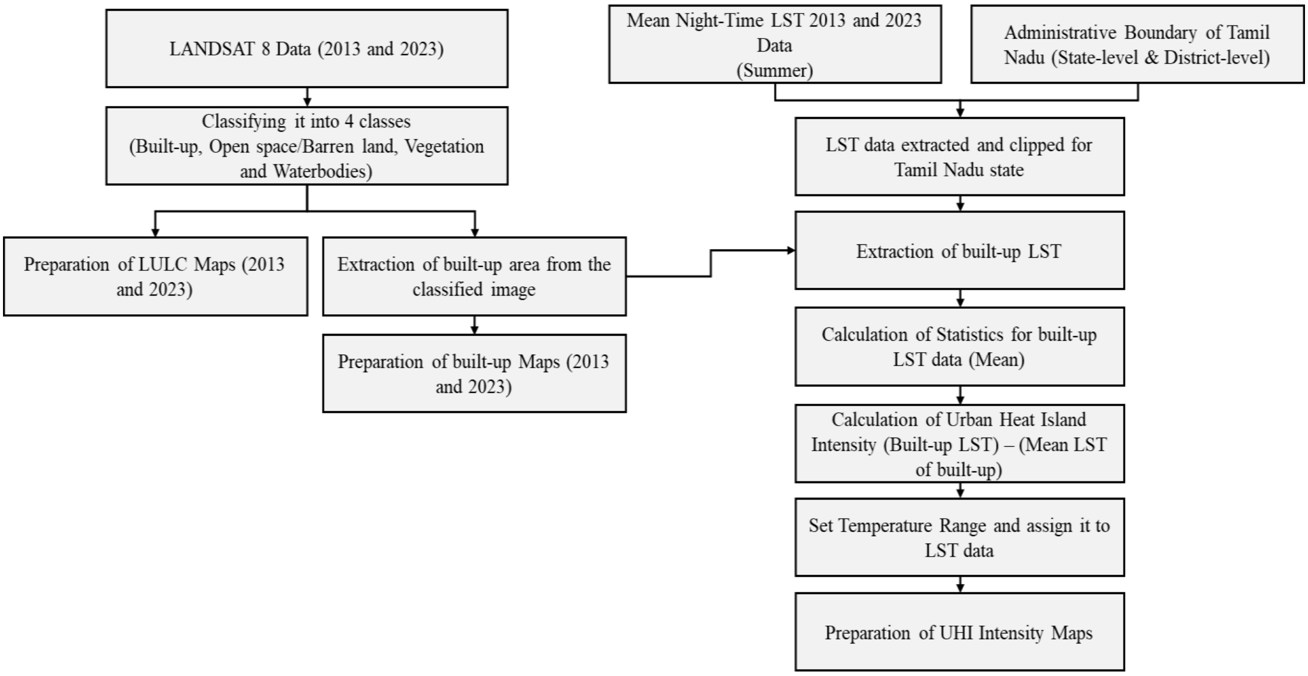


Figure 14: Methodology for mapping the UHI Intensity

2.2 STATE-LEVEL HEAT MAPS

This section discusses the spatio-temporal assessment of Land Surface Temperature at the state level. Land Surface Temperature is an indicator of surface level UHI. It differs from air temperature (the temperature given in weather reports) because land heats and cools more quickly than air, concluding as a meso (city/regional) scale assessment.

2.2.1 ASSESSMENT OF DAY AND NIGHT-TIME LAND SURFACE TEMPERATURE ACROSS SEASONS

A twenty-one-year seasonal analysis of Land Surface Temperature (LST) for Tamil Nadu state was conducted from 2003 to 2023 for daytime and night-time. To conclude the assessment, four seasons were considered- i) Summer (March to May), ii) Monsoon (June to August), iii) Post Monsoon (September to November), and iv) Winter (December to February), respectively.

Daytime and Night-time Land Surface Temperature data was categorized into various temperature ranges showing detailed analysis of temperature trends in different seasons for the state of Tamil Nadu. By identifying areas falling within the maximum temperature range for each season, significant trends in LST changes were obtained for the state within the time span of 2003 to 2023.

***Note: -** For the monsoon and post-monsoon season, cloud-free data was not available for some regions of Tamil Nadu. Thus, those datasets were neglected from the analysis.*

MEAN DAY-TIME LAND SURFACE TEMPERATURE OF SUMMER FROM 2003 TO 2023

The mean daytime LST of summer for the years 2003, 2013, and 2023 has been analyzed, with a focus on two critical temperature ranges of 41°C to 45°C and 46°C to 50°C, which covered most of Tamil Nadu's geographical area. Figure-15 displays the trends in the summer mean daytime LST. For the Summer season, in 2003, 42.3% of the state experienced mean daytime LST ranging from 41°C to 45°C, with a significant portion. However, 31.7% experienced even higher LST between 46°C to 50°C. This suggests that the area had a substantial amount of heat that year. However, by 2013, while the proportion experiencing temperatures between 41°C to 45°C increased to 45.5%, the percentage of people suffering extreme heat between 46°C to 50°C decreased to 23.2%. The results imply that some adaptation or mitigation strategies were adopted to lessen the effects of the excessive heat in that year. By 2023, although the percentage of areas experiencing temperatures between 41°C to 45°C slightly reduced to 39.8%, a notable reduction in the area subjected to extreme heat was observed with only 3.5% facing temperatures between 46-50°C. This indicates a potential trend towards improved heat resilience or climate management strategies in the state over the years. Even though there was a general drop-in daytime LST in 2023, some cities- like Chennai, Thoothukudi, Madurai, and the central part of the state continued to see greater Land Surface Temperatures (as illustrated in Figure-15).

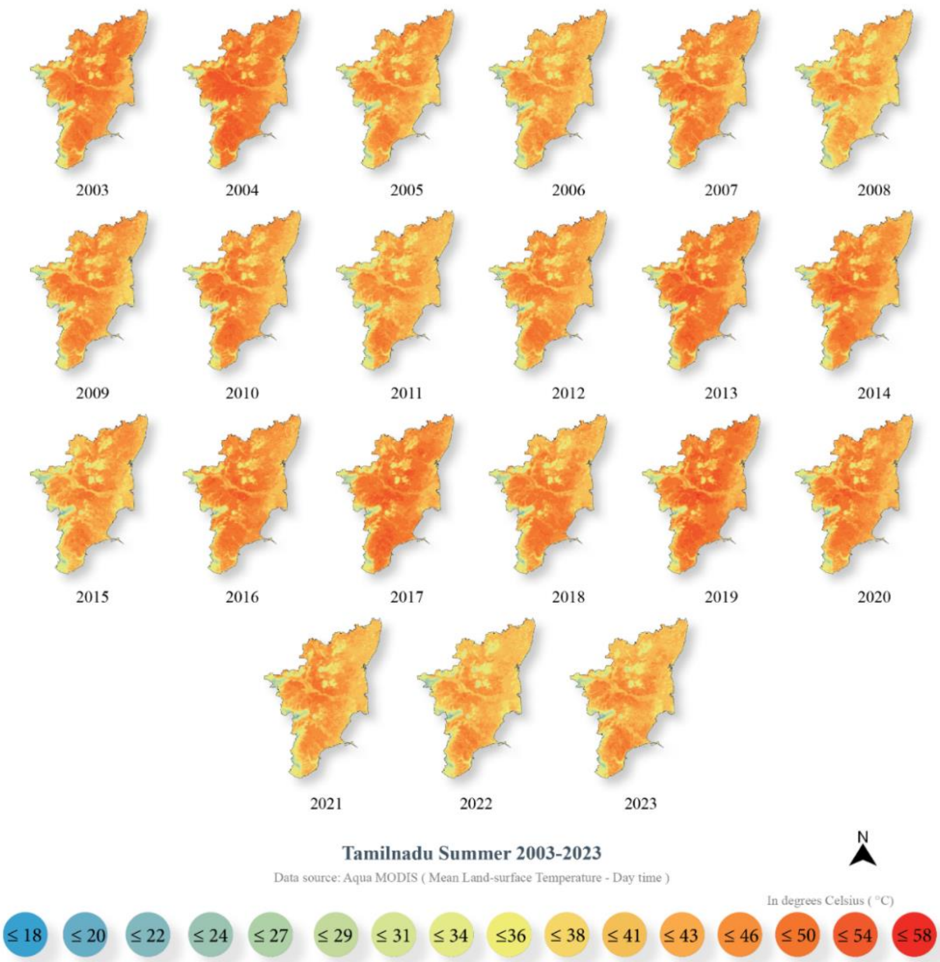


Figure 15: Day-time Mean LST Maps for Summer 2003-2023

MEAN DAY-TIME LAND SURFACE TEMPERATURE IN MONSOON 2003-2023

Mean Day-time Land Surface Temperature Maps were prepared for the Monsoon season (June, July, and August) spanning from 2003 to 2023, as shown in Figure-16. The temperature ranges of 36-40°C and 41-45°C were focused on, as these ranges covered the majority of the state.

There was a noticeable change in Tamil Nadu's monsoon season Land Surface Temperatures between 2003 and 2023. In 2003, 32.1% of the state experienced mean daily Land Surface Temperatures (LST) between 36-40°C, while 39.4% faced temperatures between 41-45°C. In 2013, the percentage of places with temperatures between 36-40°C increased slightly to 36.3%, while the percentage of places with temperatures between 41-45°C decreased to 23.8%. But by 2023, the number of areas with temperatures between 36-40°C increased considerably to 41%, while 26.2% of locations had temperatures between 41-45°C. The southern parts of the state recorded the highest amount of daytime LST followed by the coastal regions, while the western region experienced comparatively lower LST levels in comparison.

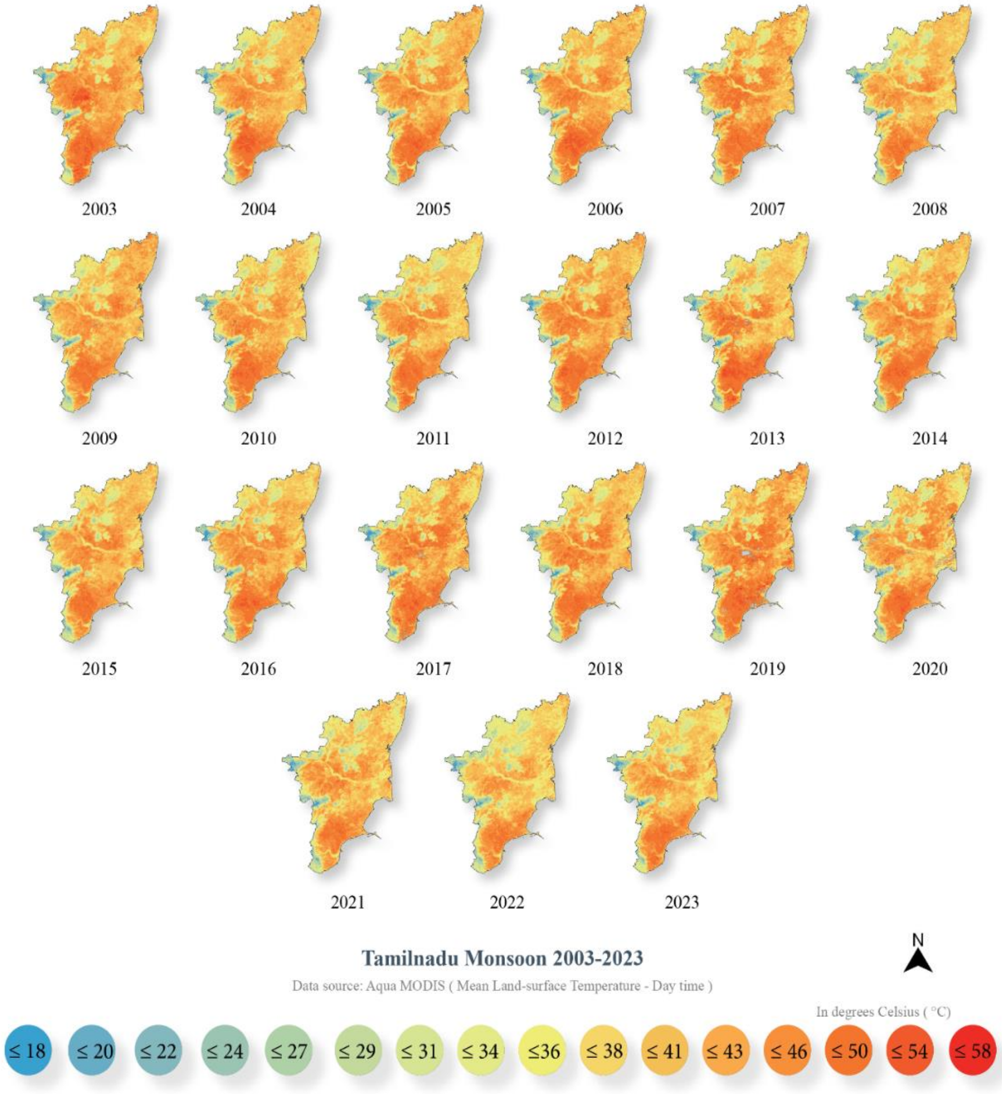


Figure 16 : Day-time Mean LST Maps for Monsoon 2003-2023

MEAN DAY-TIME LAND SURFACE TEMPERATURE IN POST MONSOON 2003-2023

Mean Day-time Land Surface Temperature Maps were generated for the Post Monsoon season spanning from 2003 to 2023 as shown in Figure 17. The analysis focused on the temperature ranges of 31-35°C and 36-40°C, since these temperature ranges covered the majority of the state.

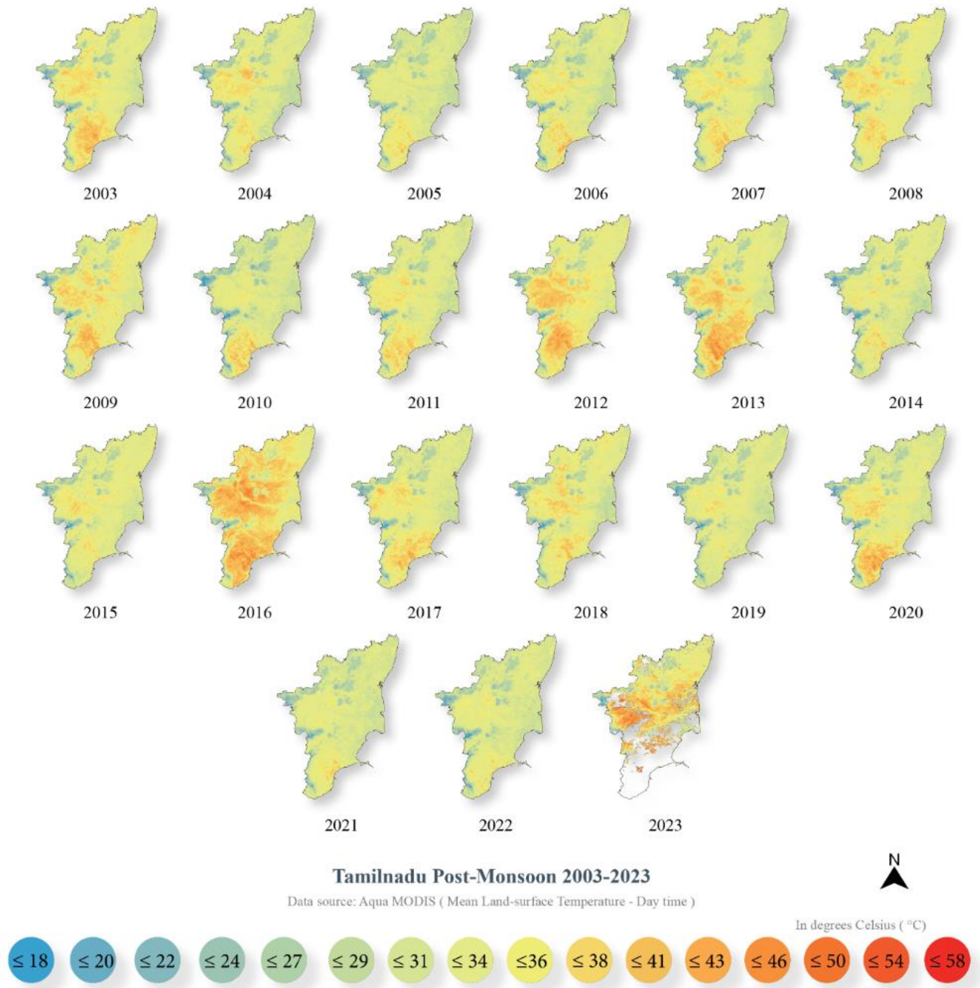


Figure 17 : Day-time Mean LST Maps for Post Monsoon 2003-2023

During the Post Monsoon season in 2003, Land Surface Temperatures in almost half of Tamil Nadu, around 56.6%, were moderate, ranging from 31-35°C, while 16.3% saw higher LST, reaching 36- 40°C. In 2013, the percentage of locations with temperatures between 31-35°C dropped to 45.3%, while 25.3% of regions had temperatures between 36-40°C. Following this pattern, by 2023, only 42.1% of places had temperatures between 31-35°C, while 30.9% of places had temperatures between 36-40°C. Over the course of two decades, this moving pattern demonstrates how the climate dynamics have changed in various locations of Tamil Nadu. Metropolitan areas and smart cities faced the maximum day-time LST across the span as compared to other rural areas during Post Monsoon.

MEAN DAY-TIME LAND SURFACE TEMPERATURE IN WINTER 2003-2023

The temperature ranges of 36-40°C and 41-45°C were focused on in the analysis of winter daytime Land Surface Temperatures for the years 2003, 2013, and 2023 in Tamil Nadu state, as these ranges covered the majority of the state. Figure 18 displays the trends in the winter mean daytime temperature over time.

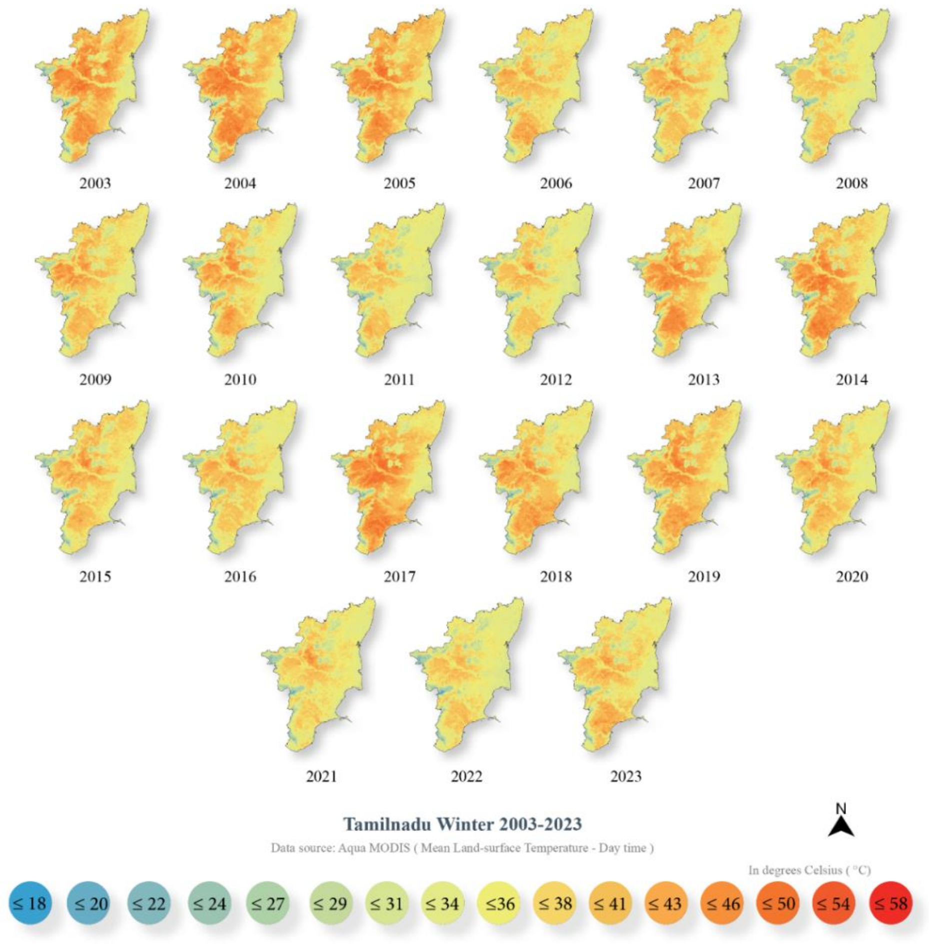


Figure 18: Day-time Mean LST Maps for Winter 2003-2023

In 2003, the mean daily temperature in 36.7% of Tamil Nadu was between 36-40°C, while 32.5% of the state had temperatures between 41-45°C. By 2013, there was a slight increase in the percentage experiencing temperatures between 36-40°C, rising to 37.7%, while 22.1% faced temperatures between 41-45°C. However, by 2023, the percentage of places with temperatures between 36-40°C had increased noticeably to 40.8%, while 6.9% of locations had temperatures between 41-45°C. These findings suggest potential changes in the winter climate of the state over the examined years.

Based on the analysis, the maximum daytime Land Surface Temperature varies across different seasons and years within the Tamil Nadu State. The highest mean daytime LST value for the summer season was about 55°C in the years 2014, 2017, and 2019; for the Monsoon season, it was 57°C in the year of 2013. The post-monsoon season in 2023 recorded a maximum daytime LST of around 51°C, and for the Winter season, around 49°C was experienced in the year 2019, with metropolitan areas experiencing the highest daytime LST across the state. Understanding these patterns is important for adapting mitigation strategies against extreme heat events.

MEAN NIGHT-TIME LAND SURFACE TEMPERATURE IN SUMMER 2003-2023

The mean night-time Land Surface Temperatures during the summer seasons over the years of 2003, 2013, and 2023 were analyzed, with specific concentration on temperature intervals of 21-23°C and 24-26°C, which covered a significant portion of Tamil Nadu state. That displays the evolving trends in the summer mean night-time LST over time. As per the analysis, there has been a steady rising trend in Tamil Nadu's summer night-time LST throughout the years as shown in Figure . Approximately 74.2% of the state had mean daily night-time Land Surface Temperatures (LST) in the range of 21–23°C in 2003, while 14.7% experienced warmer weather in the 24-26°C range. While the proportion of places with night-time LSTs between 21-23°C had declined to 71.6% by 2013, there was a corresponding increase in regions experiencing temperatures between 24-26°C, rising to 18.4%.The most significant change was observed in 2023, 62.3% of places had LST between 21-23°C, while 23.5% experienced LST between 24-26°C showing a consistent increase in the state's nigh-time LST for summer season. As evident from the maps, coastal regions experienced the maximum and western region experienced the minimum LSTs compared to other parts of the state for the summer season.

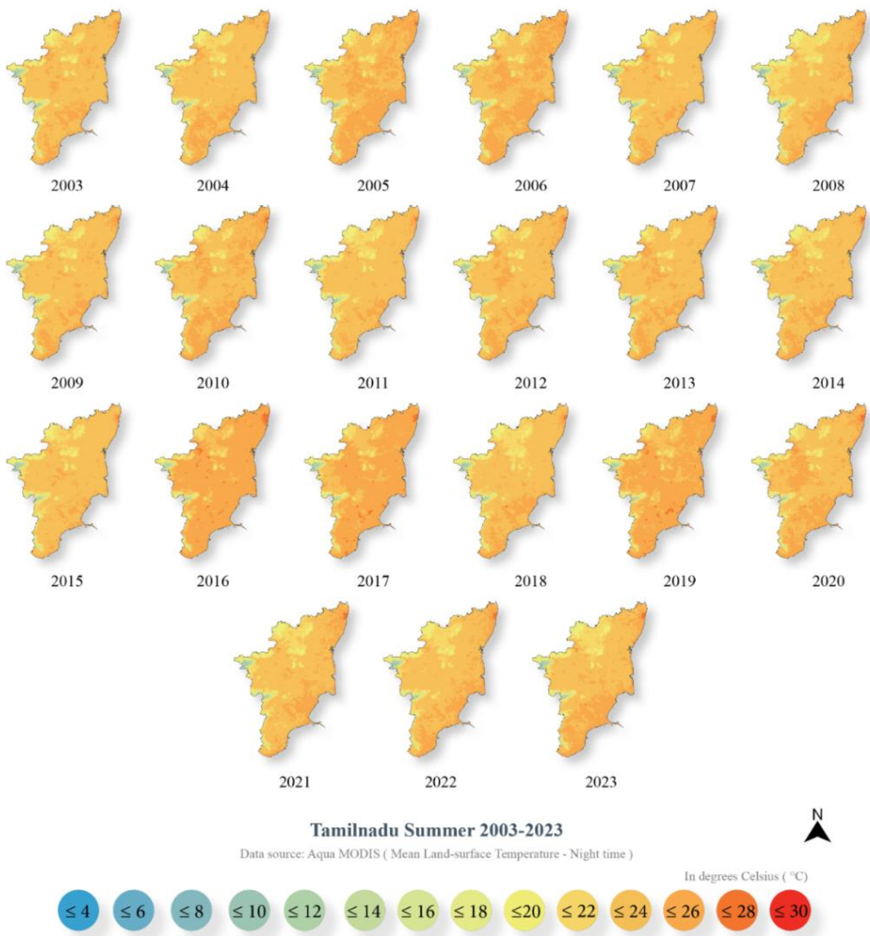


Figure 19: Night-Time Mean LST Maps for Summer 2003-2023

MEAN NIGHT-TIME LAND SURFACE TEMPERATURE IN MONSOON 2003-2023

Mean Day-time Land Surface Temperature Maps were prepared for the Monsoon season (June, July, and August) spanning from 2003 to 2023 as shown in Figure-20. The temperature ranges of 21-23°C and 24-26°C were focused on, as these ranges covered the majority of the state.

In Tamil Nadu, notable variations in the region's night-time Land Surface Temperatures (LST) were seen in the monsoon seasons of 2003, 2013, and 2023. In 2003, the mean daily night-time LST for 41.7% of the state was between 21-23°C, while 44.9% experienced LST between 24-26°C. The percentage of places with LSTs between 21-23°C increased to 46.3% by 2013, while the percentage of places with LSTs between 24-26°C fell to 36.3%. However, the most significant shift occurred by 2023, with 32.68% of locations registering LST between 21-23°C, while 53.9% experienced LST between 24-26°C, showing a significant change in the patterns of night-time LST throughout time. For monsoon season, maximum day-time LST was experienced by the metropolitan areas of the state where urban population is high.

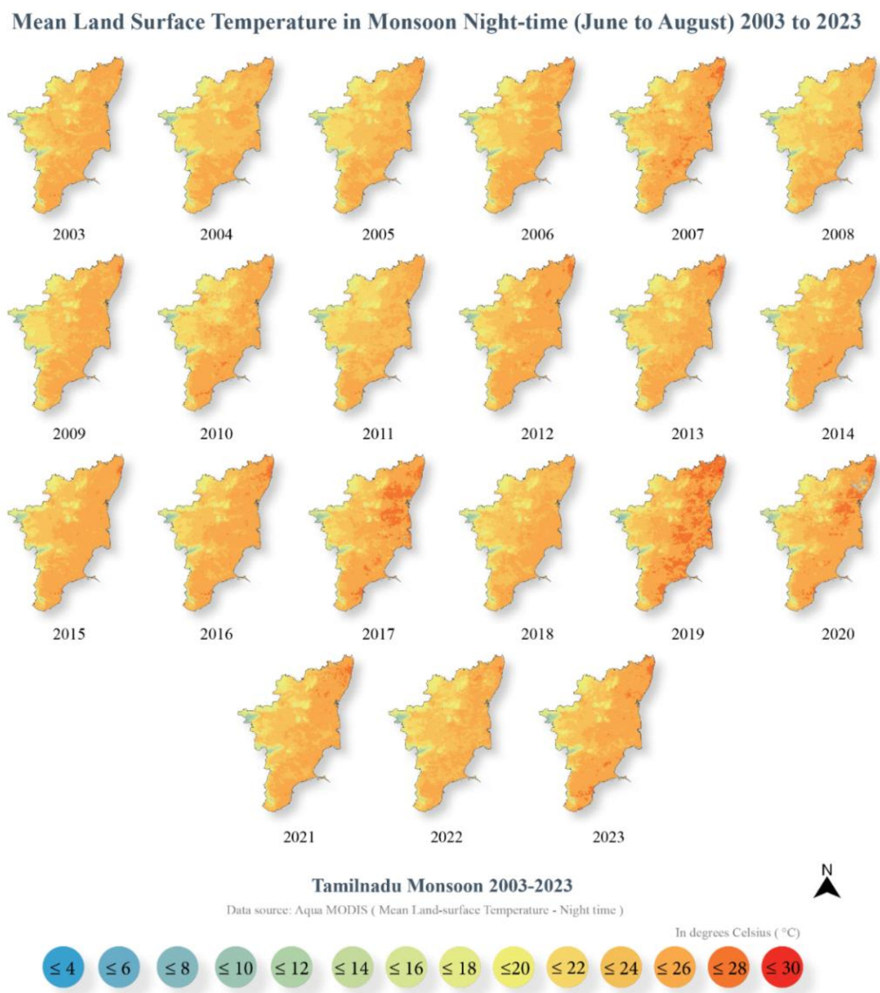


Figure 20: Night-Time Mean LST Maps for Monsoon 2003-2023

MEAN NIGHT-TIME LAND SURFACE TEMPERATURE IN POST MONSOON 2003-2023

Mean Night-Time Land Surface Temperature Maps were generated for the Post Monsoon season spanning from 2003 to 2023 as shown in Figure-21. The analysis focused on the temperature ranges of 18-20°C and 21-23°C, since these temperature ranges covered the majority of the state. For Post monsoon season in the year of 2003, the percentage of region experiencing night-time LST within the range of 18-20°C was 55.5% while 29.7% experienced LST between 21-23°C range. By 2013, there was a notable decrease in areas with LST between 18-20°C, declining to 29.7%, while the proportion experiencing temperatures between 21-23°C decreased slightly to 24.8%. However, the most significant shift occurred in 2023, with 16% of locations experiencing LST between 18-20°C, while 53.8% experienced temperatures between 21-23°C. This suggests that patterns of night-time LST had changed significantly over time. As evident from the maps, coastal regions experienced the maximum and western region experienced the minimum LSTs compared to other parts of the state for the post monsoon season with the central region experiencing moderate LSTs.

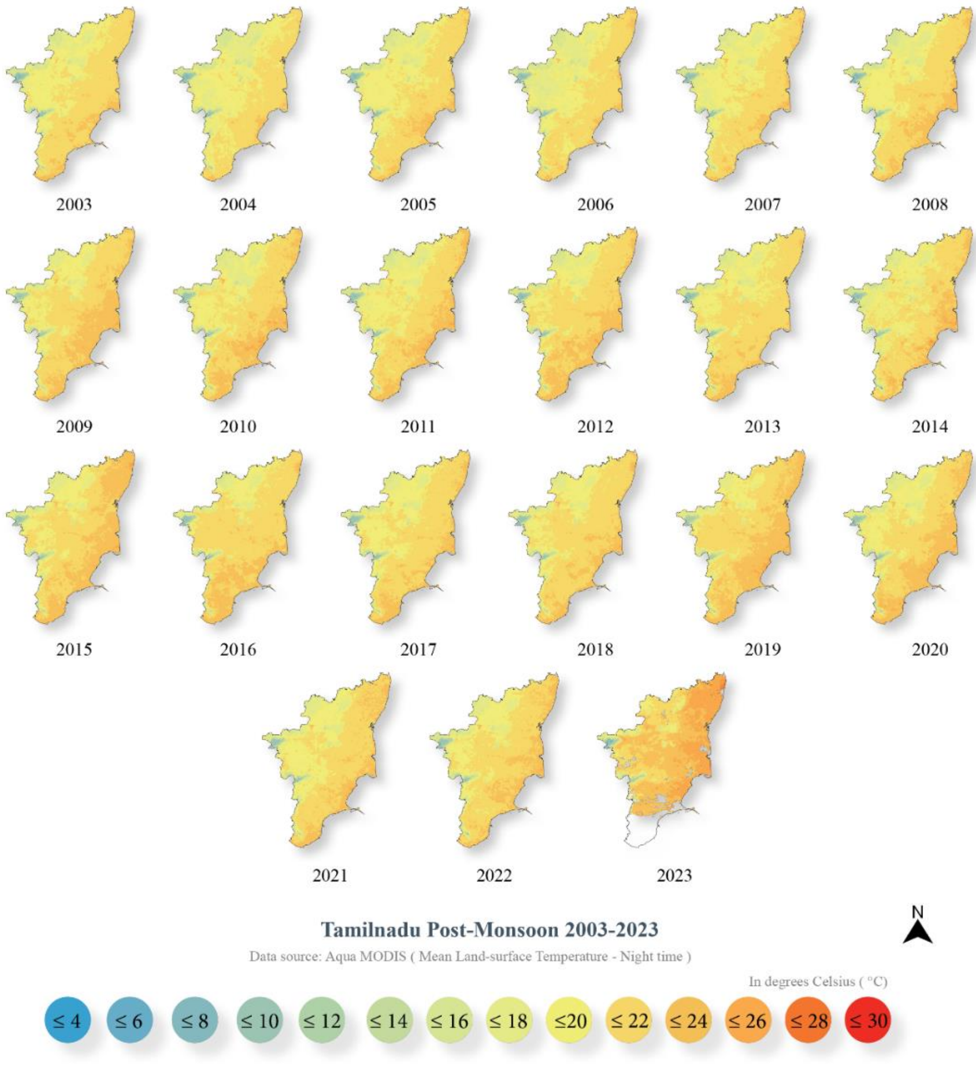


Figure 21: Night-Time Mean LST Maps for Post Monsoon 2003-2023

MEAN NIGHT-TIME LAND SURFACE TEMPERATURE IN WINTER 2003-2023

The winter night-time Land Surface Temperatures for the years 2003, 2013, and 2023 in Tamil Nadu state were analyzed, with a focus on the temperature ranges of 17-19°C and 20-22°C, since these temperature ranges covered the majority of the state. The Figure-22 displays the trends in the winter mean daytime temperature over time.

In 2003, the mean daily LST in 33.5% of Tamil Nadu was between 17-19°C, while 60.5% of the state had temperatures between 20-22°C. By 2013, there was an increase in the percentage experiencing LST between 17-19°C, rising to 48.7%, while 42.4% faced temperatures between 20-22°C.

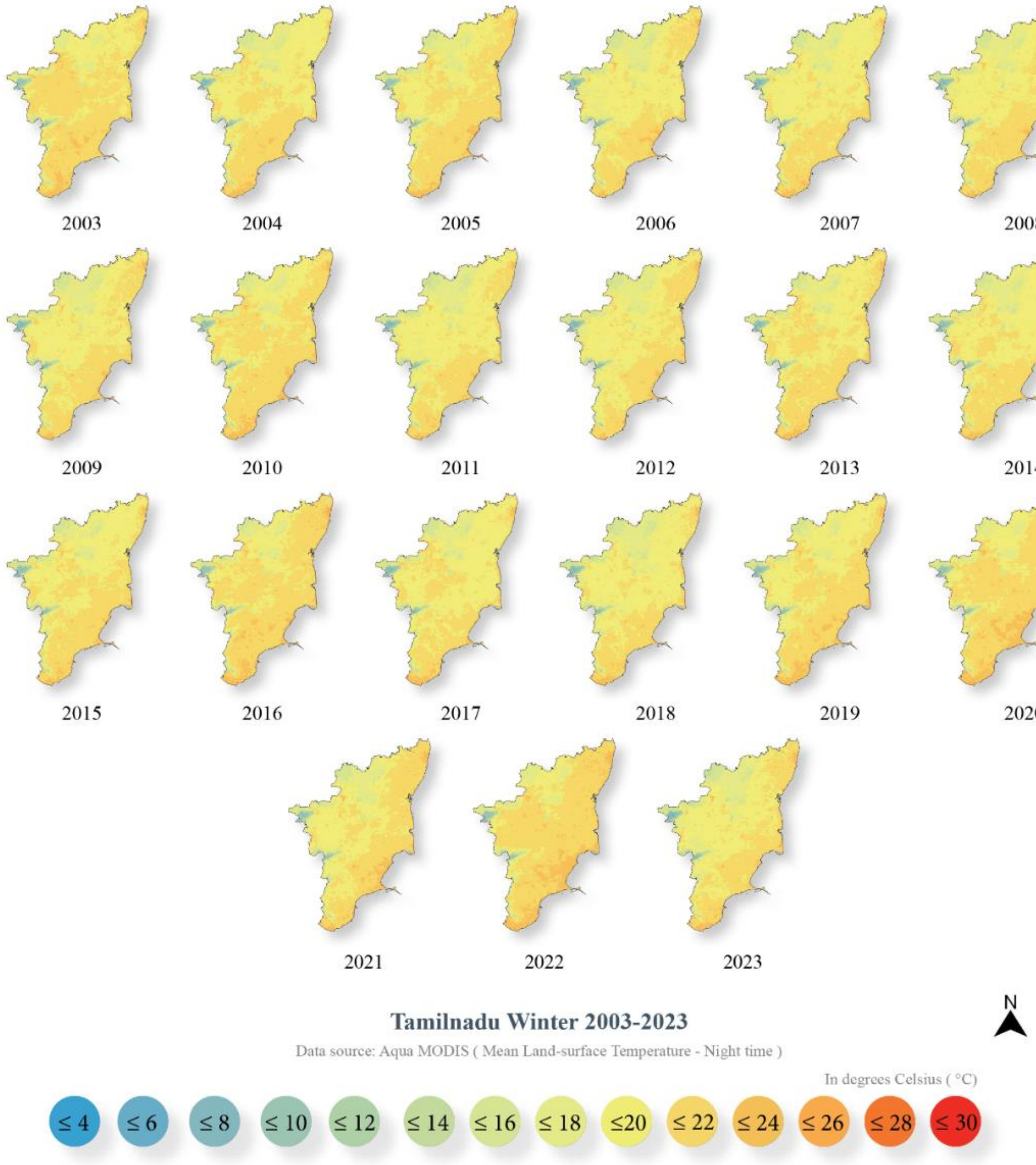


Figure 22: Night-Time Mean LST Maps for Winter 2003-2023

However, by 2023, the percentage of places with temperatures between 17-19°C had increased noticeably to 53.25%, while 34.1% of locations had temperatures between 20-22°C. These findings suggest potential changes in the winter climate of the state over the examined years.

The Land Surface Temperature (LST) trend analysis shows a notable increase over the course of two decades, which can be attributed to a variety of prevailing conditions and reasons. This analysis reveals significant variations in maximum night-time LST across different seasons and years in Tamil Nadu. In summer season of 2023, the highest mean night-time LST value was about 29°C. Similarly, for Monsoon season, both 2013 and 2023 years witnessed the highest mean night-time LST of around 28°C. The Post Monsoon season in 2023 recorded a maximum night-time LST of around 27°C and for the Winter season it was around 25°C in the year of 2019 and 2003, displaying the seasonal contrast in the night-time LSTs. Higher Land Surface Temperature values were observed in the metropolitan regions of the state due to the presence of high urban population density. Understanding these patterns are important for adapting mitigation strategies against extreme heat events, enhancing the region's resilience to the climate impacts.

2.2.2 TRENDS OF NIGHT-TIME LST CHANGE OVER THE YEARS (2003 & 2023)

When observing LST trends, it is observed that the Surface Urban Heat Island (SUHI) is most critical during night-time. Thus, night-time LST has been considered for identifying the trends from the year 2003-2023.

The spatio-temporal changes in mean night-time LST for four seasons (summer, monsoon, post-monsoon, and winter) in a given year have been computed between 2003 and 2023. Mean Night-time LST data for two years 2003 and 2023 were acquired for all four seasons, allowing for a comparison of LST trends over two decades. The difference in LST between the two years was calculated by subtracting the 2003 LST from the LST of 2023, identifying changes in night-time LST patterns over the time span.

The difference map has been divided into colour gradient ranging from blue colour (denoting a decrease in night-time LST) to red colour (denoting an increase in LST), with yellow colour representing no significant change. Smart cities were considered for the analysis due to dense urban population.

During summer season, significant rise in night-time LST (please refer to Figure-23)was observed predominantly around metropolitan areas of the Tamil Nadu state. Specifically, there was an increase of about 3°C in LST for cities such as Chennai and Vellore, around 2°C for Thoothukkudi, Madurai, and Tiruchirappalli, and about 1.5°C rise for Tirunelveli.

During Monsoon season, notable increase in night-time LST was observed. Specifically, an increase of approximate 4°C in night-time LST for cities such as Chennai, Vellore, and Tiruchirappalli. Moreover, cities such as Tiruppur and Coimbatore experienced an increase of about 3°C, while Madurai and Thoothukkudi saw an increase of about 2°C between the years 2003 and 2023 (refer to Figure-23).

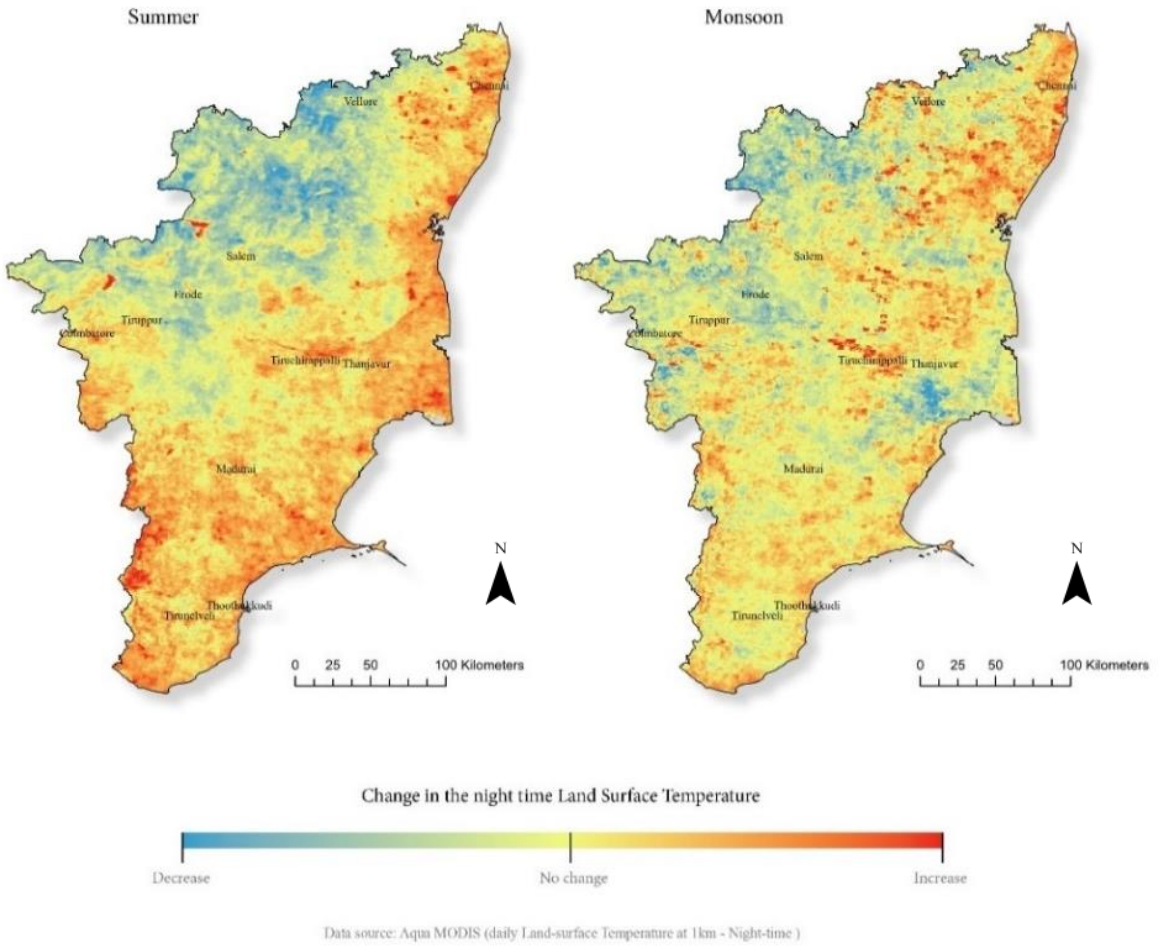


Figure 23: Change in Night-time LST from 2003 to 2023 (Summer and Monsoon)

Significant increases in the Land Surface Temperature (LST) at night have been seen in a number of cities during the Post Monsoon season (as illustrated in Figure-24). Notably, Chennai experienced a significant rise of about 4 °C in night-time LST, while Thoothukkudi and Vellore experienced a rise of around 3°C. Cities like Erode, Madurai, and Coimbatore recorded an increase of about 2.5°C.

Difference maps were also generated for winter season indicating notable rise in night-time LST for various cities across Tamil Nadu. Thoothukkudi experienced the most significant rise with an increase of approximately 3.5°C, followed by Vellore with a rise of about 2.5°C. Additionally, Chennai and Madurai saw an increase of around 2°C in mean night-time LST (refer to Figure-24).

These night-time LST difference maps show how Urban Heat Island effects have increased across different seasons over span of over two decades providing insights of how night-time LST has increased in different parts of the Tamil Nadu state.

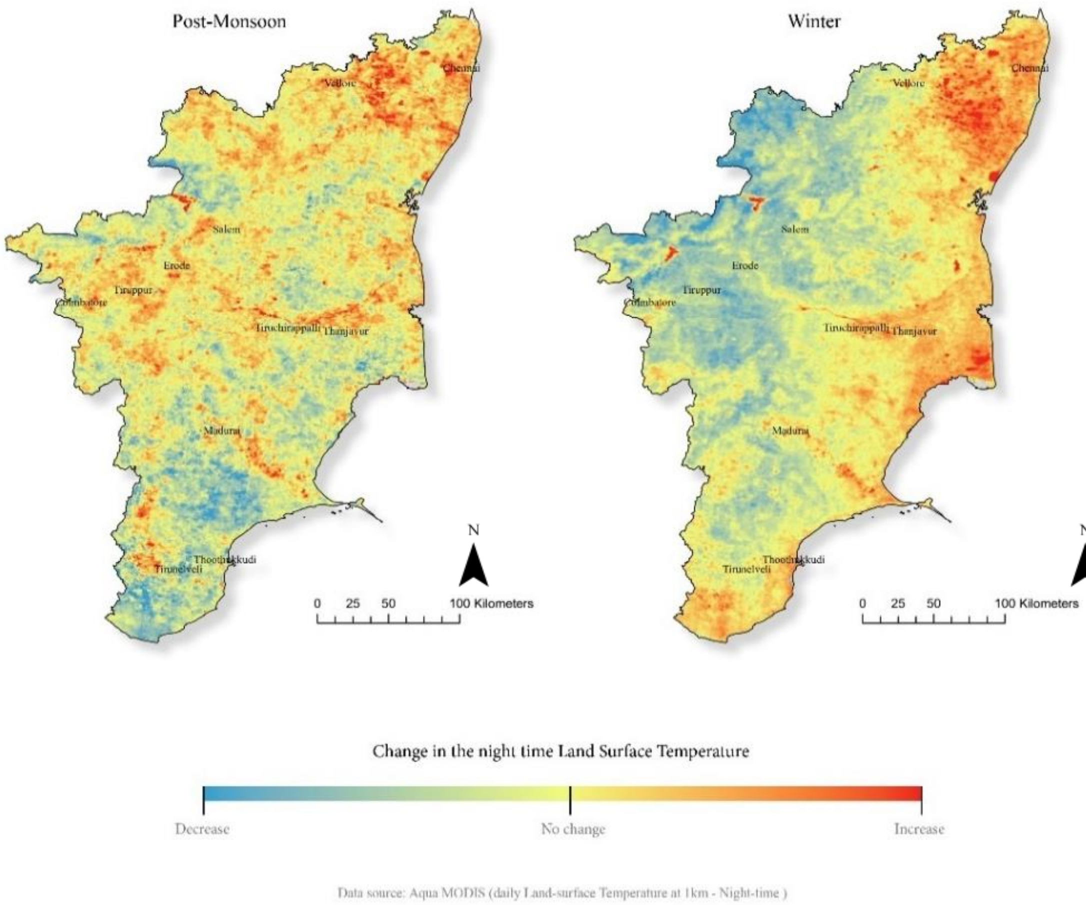


Figure 24: Change in Night-time LST from 2003 to 2023 (Post Monsoon and Winter)

2.3 DISTRICT-LEVEL HEAT ZONES

This chapter also discusses about the spatio-temporal assessment of Land Surface Temperature at the district level followed by identification of heat zones.

2.3.1 IDENTIFICATION OF DISTRICT LEVEL HEAT ZONES

A heat zone refers to a geographical region characterized by high temperatures as compared to its surrounding areas. Identification of Heat Zones is necessary to understand the climate patterns, assessing potential risks associated with heat stress and implementation of strategies for mitigating adverse effect of extreme heat experienced by community as well as environment.

The surface temperature of Tamil Nadu state was determined from the satellite data. Moderate Resolution Imaging Spectroradiometer (MODIS) instrument detects the radiation emitted by the surface and from the detected readings, surface temperatures are estimated for every square kilometre of earth. The LST for every square kilometre of the state was captured and averaged. To mitigate anomalies in an individual year data, average of three-year periods was computed providing a more stable representation of LST trends over time period.

THREE YEAR MEAN TEMPERATURE (DAY-TIME)

To identify district level heat zones in Tamil Nadu, the day-time mean Land Surface Temperature over the three-year intervals was analysed for the periods 2001-2003, 2011-2013, 2017-2020 and 2021-2023. This approach provides a comprehensive understanding daytime of LST trends across different time periods providing areas experiencing constant heat (as illustrated in Figure-25).

Peak daytime mean LST in Thoothukkudi reached above 42°C between 2001 to 2003 followed by Virudhunagar and Karur district which experienced LST between 41.5°C to 42°C. In the following years of 2011 to 2013, Virudhunagar experienced peak mean daytime LST above 41.5°C followed by districts of Karur and Thoothukkudi experiencing LST between 41-41.5°C, indicating persistent high temperatures. For the period of 2017 to 2020, Karur, Virudhunagar and Thoothukkudi experienced mean LST of above 42°C. And for the year of 2021 to 2023, maximum daytime mean LST was experienced by Karur and Chennai which was above 40°C. Overall, these observations give an insight of prevalence of high daytime LST in various districts of Tamil Nadu over different time periods.

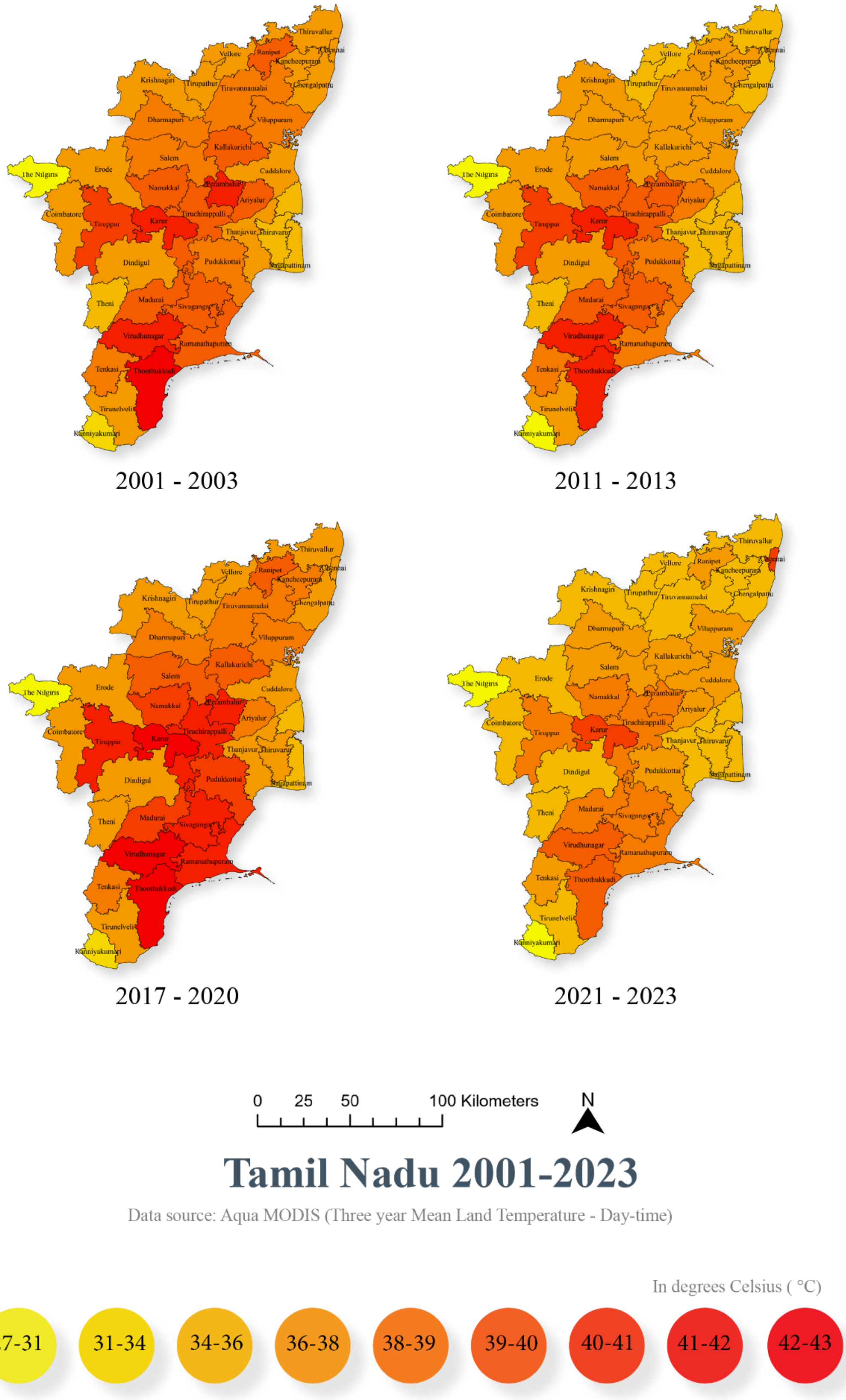


Figure 25: Average 3-year Mean daytime land surface temperature- i)from 2001 to 2003, ii) from 2011 to 2013, iii) from 2017 to 2020, and iv) from 2021 to 2023.

THREE YEAR MEAN TEMPERATURE (NIGHT-TIME)

To identify district level heat zones in the state, the night-time mean Land Surface Temperature over the three-year intervals was analysed for the periods 2001-2003, 2011-2013, 2017-2020 and 2021-2023. This approach provides a comprehensive understanding of night-time LST trends across different time periods providing areas experiencing constant heat (as illustrated in **Error! Reference source not found.**).

For the time period of 2001-2003, Chennai recorded highest mean night-time LST of about 23°C, with Thoothukkudi and Ramanathapuram experiencing LST values ranging between 22°C to 22.5°C. During the period of 2011-2013, Chennai continued to experience peak mean LST exceeding 23.5°C, followed by Thoothukkudi and Ramanathapuram with night-time LST values near to 22.5°C. Between 2017-2020, Chennai's night-time mean LST increased to 24°C while Ramanathapuram experienced LST level above 22.5°C. And for the years 2021-2023, Chennai again recorded the maximum daytime mean LST nearing 24.5°C followed by Ramanathapuram and Madurai with night-time mean LST values surpassing 22.5°C.

Mean night-time LST for the year of 2001-2003 and 2021-2023 was taken and compared to identify the change in night-time LST in the past two decades. The hottest district of the Tamil Nadu was Chennai whose temperature profile changed the most. Chennai's average night-time LST increased by 1.5°C from 23°C in 2001-2003 to 24.5°C in 2021-2023.

Surrounding districts adjoining Chennai, namely Chengalpattu, Kancheepuram and Ranipet also observed notable changes with an average increase of about 1.2°C in night-time LST during the same time span (as illustrated in Figure 7).

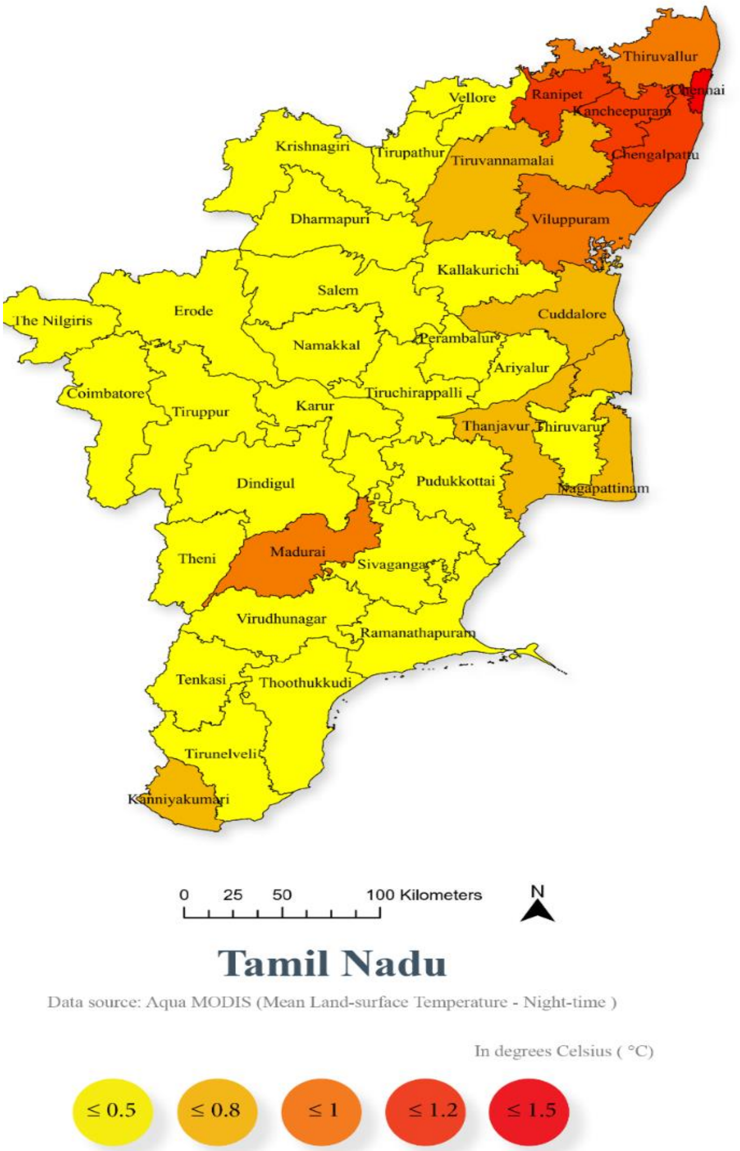


Figure 26: Hottest districts assessed from the spatio-temporal changes of LST over the last two decades

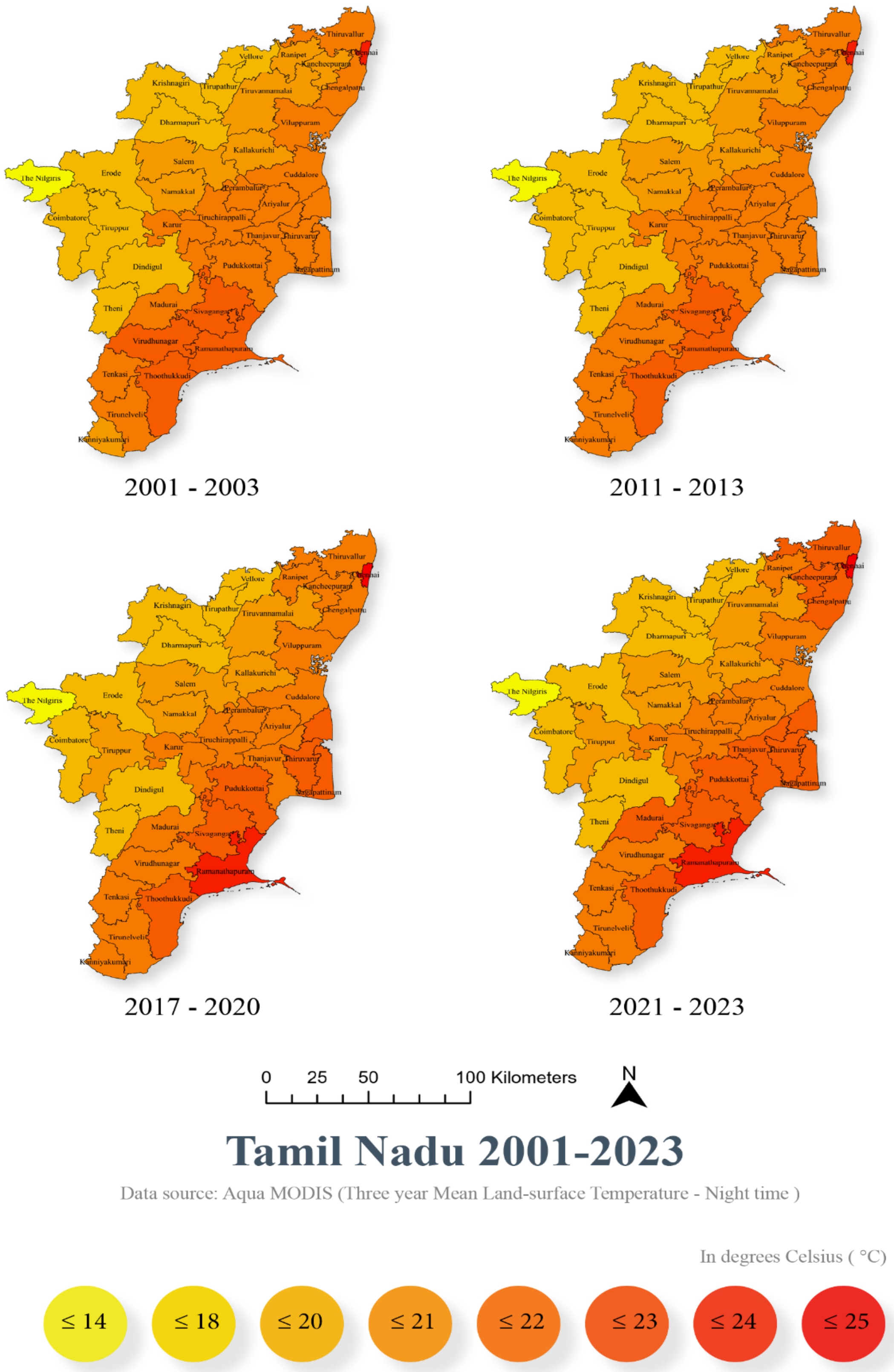


Figure 27: Average 3-year Mean night-time land surface temperature- i) from 2001 to 2003, ii) from 2011 to 2013, iii) from 2017 to 2020, and iv) from 2021 to 2023.

2.3.2 MAXIMUM AND MINIMUM RECORDED AIR TEMPERATURES

The analysis of maximum and minimum air temperature recorded offers valuable information about the temperature extremes that a particular region has experienced over given time span. The methodology involved acquiring air temperature data from 61 weather stations across the state of Tamil Nadu for the past year 2023. Daily mean temperatures for both daytime and night-time were calculated from the data acquired. From the acquired mean values, the day and night on which minimum and maximum air temperatures were experienced was identified. For further analysis, LST data was obtained for all those four months in which minimum and maximum values of daytime and night-time temperatures were experienced. Finally, by analysing this data, the districts with highest and lowest mean air temperatures were identified denoting the heat zones within Tamil Nadu.

MAXIMUM AND MINIMUM RECORDED TEMPERATURE (DAY-TIME)

Highest daytime air temperature in the year of 2023 was experienced in the month of June and minimum daytime air temperature was experienced in the month of December. During the hottest day experienced in 2023, five districts including Chennai, Ramanathapuram Thoothukkudi, Virudhunagar and Karur, recorded LST within the range of 42°C to 44°C, indicating widespread heat across the state. When coldest day was experienced, there were still few districts whose LST was above 30°C such as Chennai, Karur and central part of Tamil Nadu displaying prominent warmth even during the colder time periods (as illustrated in Figure-28).

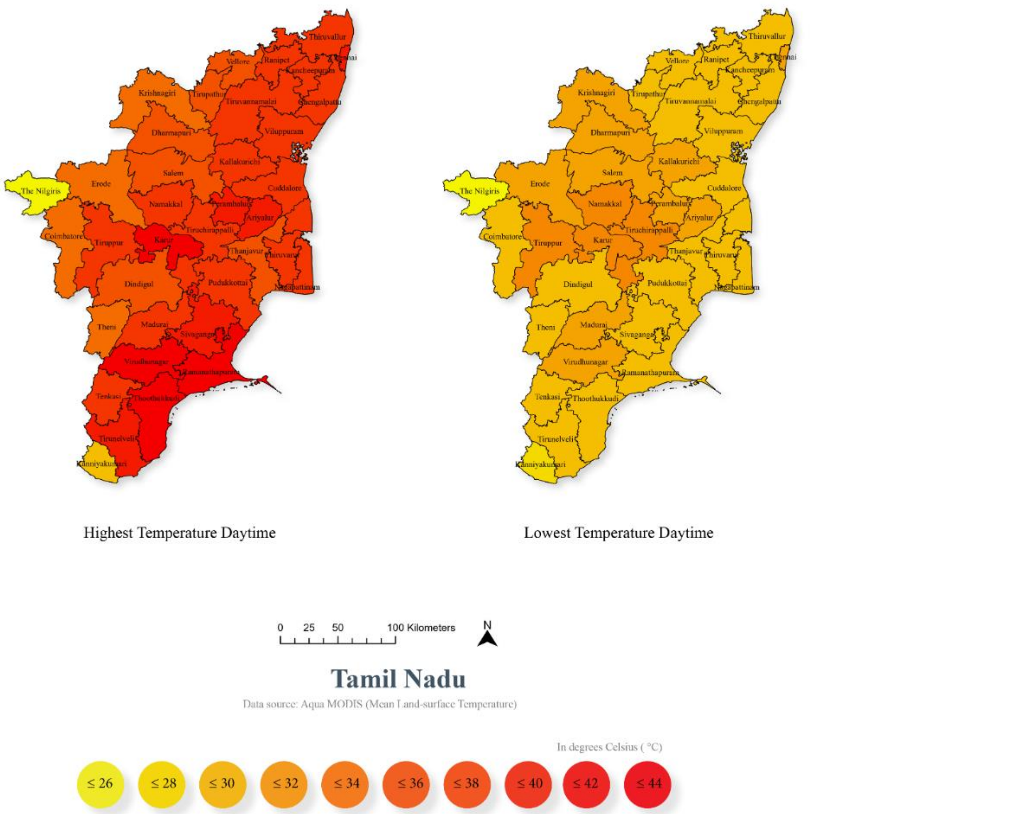


Figure 28: Maximum and Minimum LST recorded in Daytime

MAXIMUM AND MINIMUM RECORDED TEMPERATURE (NIGHT-TIME)

Highest night-time air temperature in the year of 2023 was experienced in the month of August and minimum night-time air temperature was experienced in the month of January. During the hottest night experienced in 2023, coastal regions of Tamil Nadu including Chennai, Thoothukkudi, Virudhunagar, Cuddalore and Viluppuram, recorded LST within the maximum range of 25°C to 26°C, indicating high nigh-time temperatures in these areas. When coldest day was experienced, there were still few districts whose LST was above 24°C such as Chennai and Nagapattinam, suggesting the mild conditions might persist even during colder months (as illustrated in Figure 29).

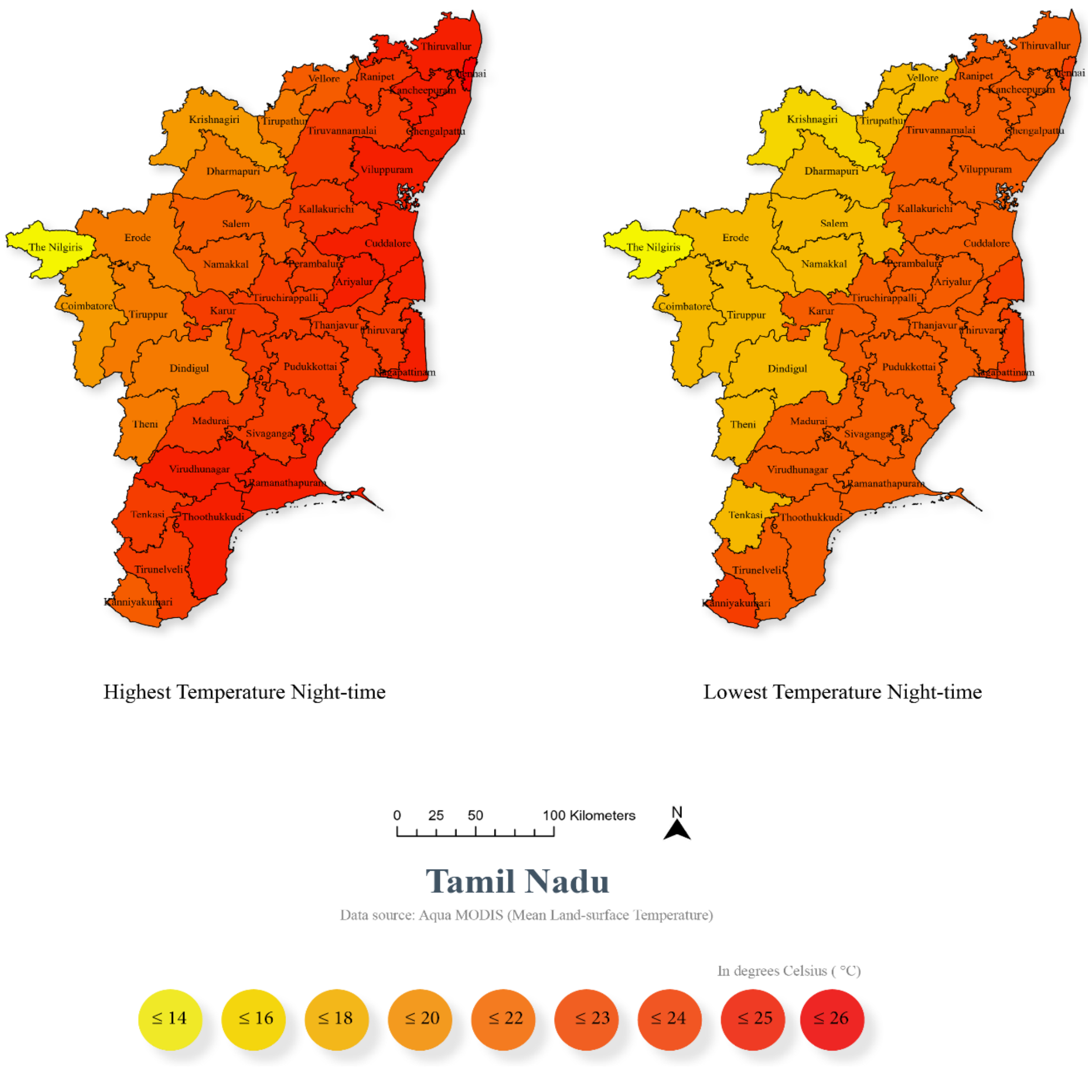


Figure 29: Maximum and Minimum LST recorded in Night-time

2.3.3 URBAN LAND SURFACE TEMPERATURE CHANGE

Urban Land Surface Temperature analysis is conducted to understand the extent of Urban Heat Islands (UHIs). UHI refers to the phenomena where urban areas experience higher temperatures as compared to surrounding rural areas due to man-made activities and infrastructures. Urban Heat Island intensity is the index which shows the presence of UHI.

For identifying Urban Heat Island intensity, summer night-time mean LST data for the years 2013 and 2023 was acquired. Additionally, LULC maps covering Tamil Nadu was created for same years using LANDSAT 8 data. First level classification was done, and it was divided into 4 classes namely Built-up, Open space/Barren land, Vegetation and Waterbodies as shown in Figure-30.

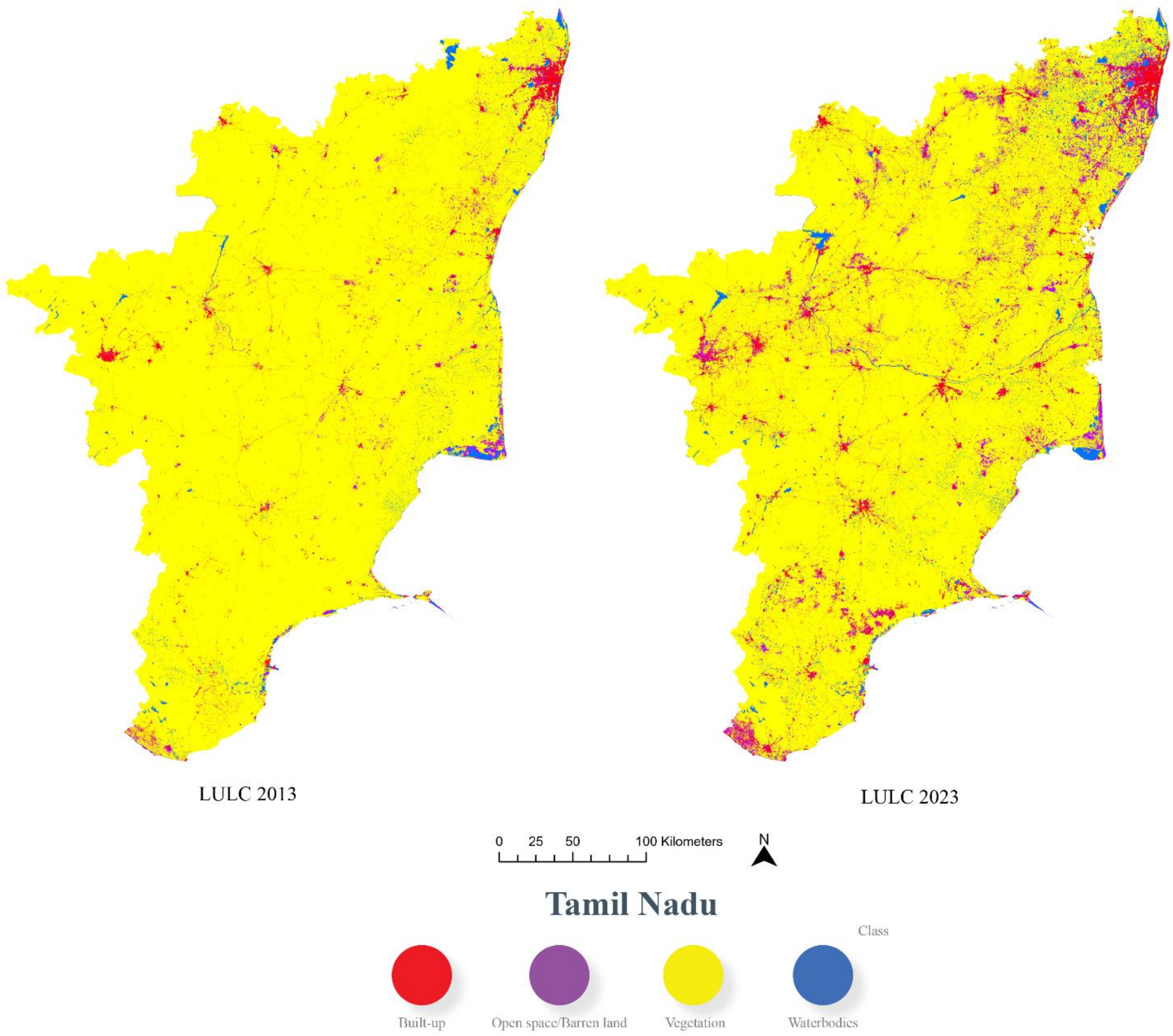


Figure 30: Land Use Land Cover Change

From the LULC, the built-up areas were extracted and from the mean LST data, LST for only built-up was extracted. Additionally, Mean Air Temperature for built-up LST was derived. Urban Heat Island Intensity was calculated for all the districts of Tamil Nadu by subtracting built-up LST with mean built-up LST. Then output of UHI Intensity was analysed to identify most significant temperature rise within urban zones. Based on intensity values, heat zones within Tamil Nadu were derived.

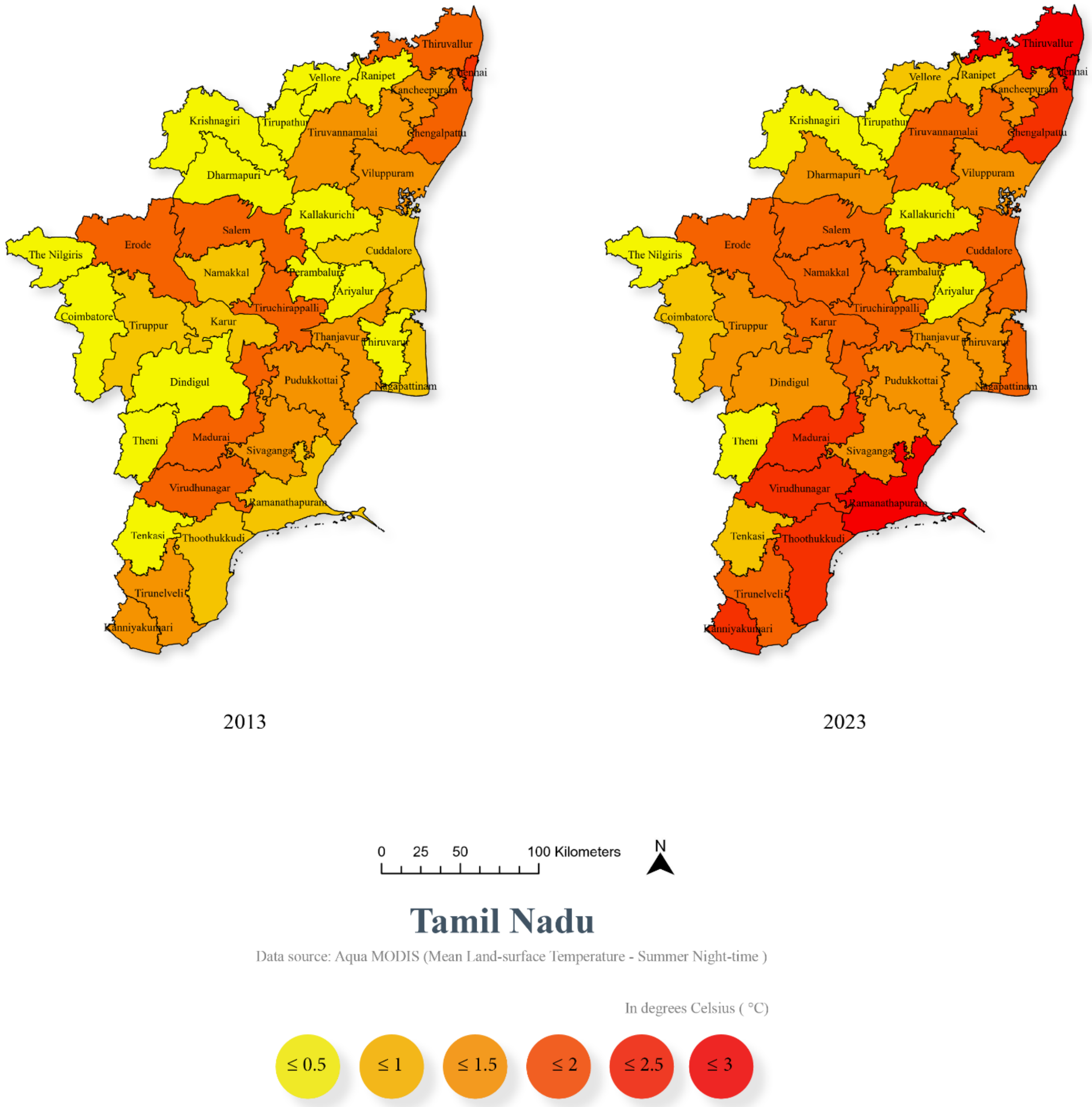


Figure 31: Urban Land Surface Temperature Change

As evitable from Figure-31, in 2013, Chennai district exhibited UHI intensity of about 2.5 °C, while other districts such as Madurai, Tiruvallur, Chengalpattu, Erode and Salem recorded values around 2°C. Whereas by 2023, there was an increase in UHI intensity, with Chennai, Thiruvallur and Ramanathapuram reaching values close to 3°C and districts like Madurai, Thoothukkudi and Virudhunagar experiencing intensities around 2.5°C.

Figure-32, shows a clear correlation between the built-up area and Urban intensity for the years of 2013 and 2023. Regions having higher levels of urban development exhibited higher Urban Intensity values, indicating more heated temperatures in these densely built-up areas whereas areas with lower concentration of built-up shows relatively lower urban intensity values, displaying reduced heated temperatures in less urbanized areas. These findings suggest significant increase in Urban Heat Island effect across various districts of Tamil Nadu in the past decade, indicating the need for focused heat mitigation strategies in these districts.

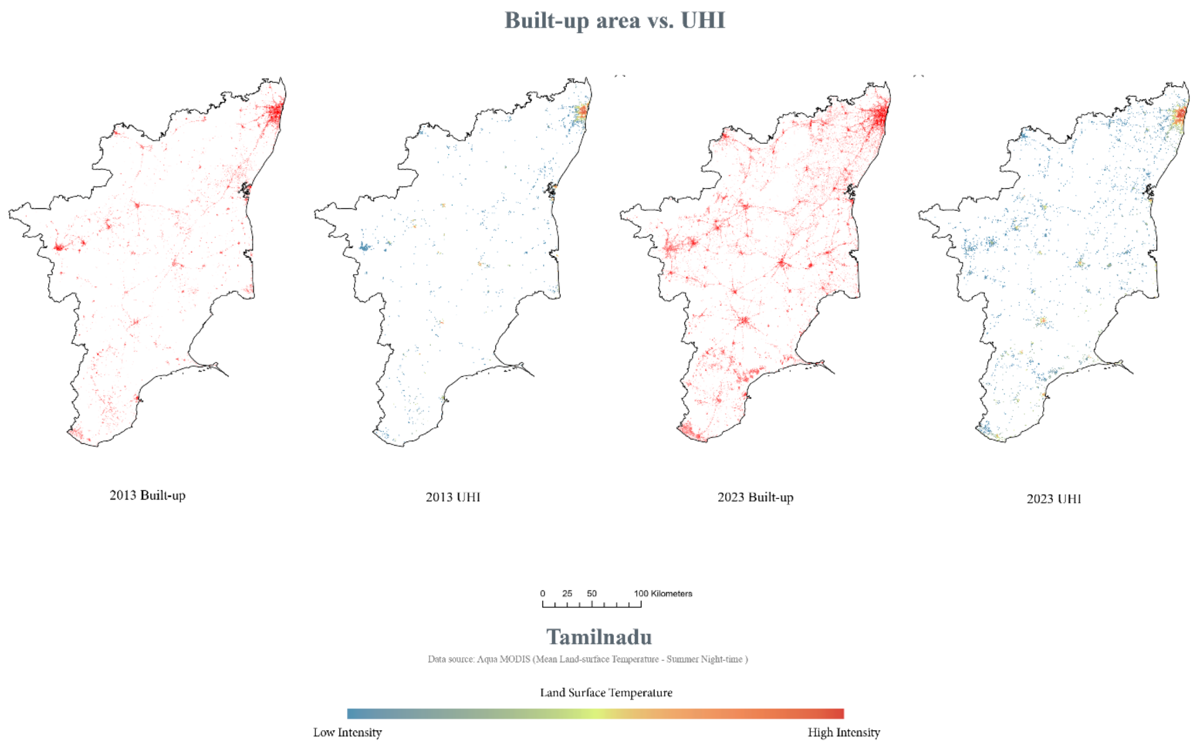
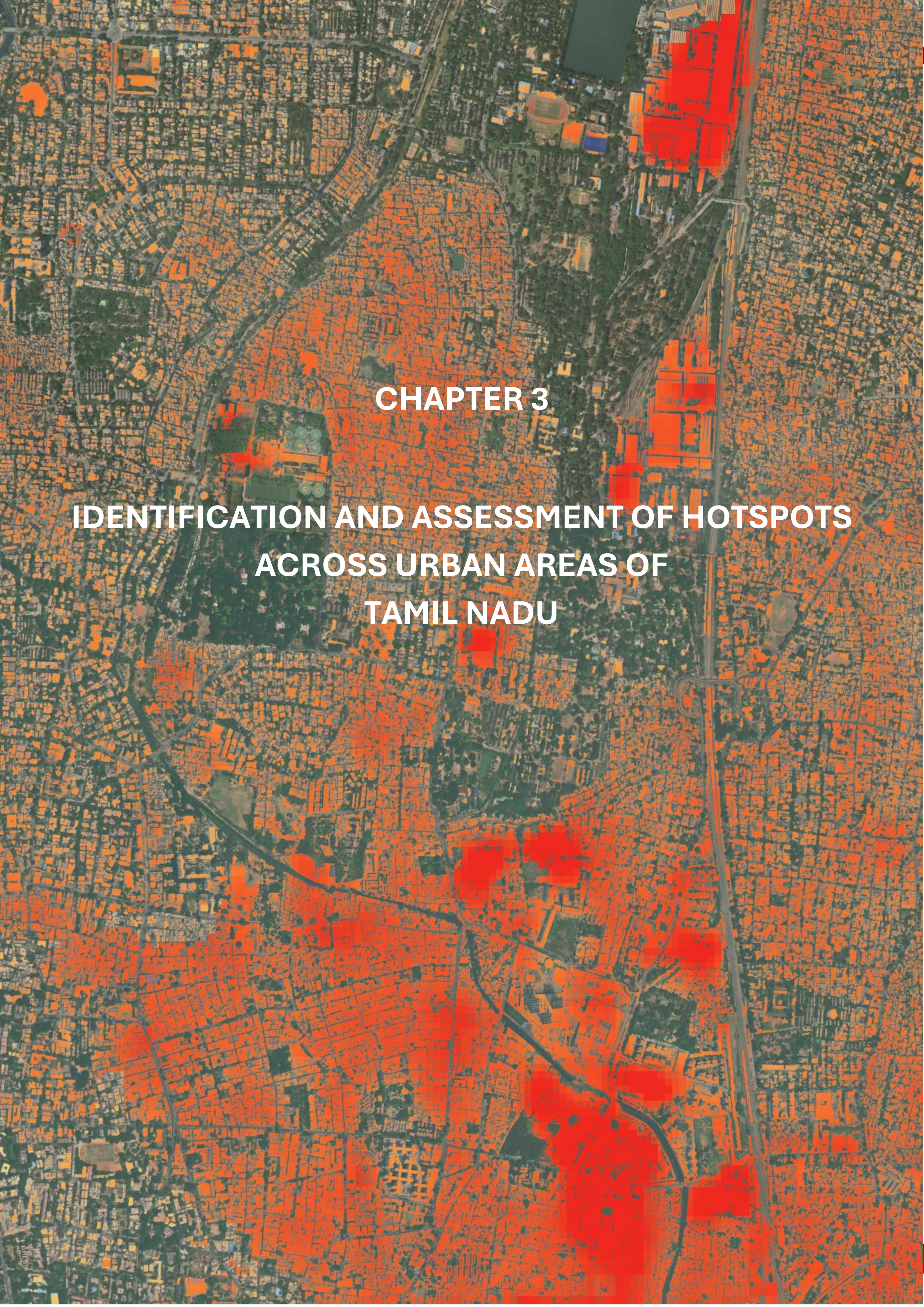


Figure 32: Built-up area vs UHI



CHAPTER 3

IDENTIFICATION AND ASSESSMENT OF HOTSPOTS ACROSS URBAN AREAS OF TAMIL NADU

SYNOPSIS

The study on Identification and Assessment of Hotspots Across Urban Areas of Tamil Nadu was conducted by CEPT University with the funding assistance from UNEP. Tamil Nadu State Land Use Research Board with the support of UNEP commissioned studies to identify vulnerable hotspots of the Urban Heat Island in the major cities of Tamil Nadu. This study aimed to conduct a Surface Urban Heat Island (SUHI) analysis, with the primary objective of mapping current hotspots across Tamil Nadu based on four land classifications: (1) Built-up, (2) Vegetation Cover, (3) Water Bodies, and (4) Barren Land. This analysis supports the development of an effective UHIE mitigation plan. The study focused on identifying and assessing hotspots across urban areas of Tamil Nadu and provided recommendations for managing UHIE mitigation in designated smart cities. To meet the study's objectives, the following actions were emphasized:

- ***Identification of Urban Hotspots**: Hotspots were identified through a systematic review of existing literature and pilot projects, utilizing sources such as the 'Literature Review and Assessment Report of UHIE in CMA' (authored by CARBSE, CRDF, and CEPT University with UNEP support).*

- ***Mapping of Spatio-Temporal SUHI Variability**: The spatial and temporal variability of the SUHI effect was mapped with a comprehensive assessment of Land Use And Land Cover (LULC) dynamics and other urban planning indicators to validate the identified hotspots.*

- ***Focused Analysis on Designated Smart Cities**: Initially, the study concentrated on 11 designated smart cities in Tamil Nadu, with two emerging cities selected for further analysis in consultation with experts.*

- ***Graded Temporal Analysis of Landscape Indices**: A temporal analysis from 2013 to 2023 was conducted using landscape indices—NDVI (Normalized Difference Vegetation Index), NDBI (Normalized Difference Built-up Index), and MNDWI (Modified Normalized Difference Water Index)—to assess the impact of urbanization and changes in blue-green cover, correlating these trends with UHIE in selected smart cities.*

- ***Targeted Recommendations for UHIE Mitigation**: Recommendations for UHIE mitigation were provided based on an evaluation of the urban characteristics of each hotspot across the two selected cities.*

The methodology assessed Land Surface Temperature (LST) across 11 smart cities: Chennai, Coimbatore, Madurai, Salem, Thanjavur, Vellore, Thoothukkudi, Tirunelveli, Tiruppur, Tiruchirappalli, and Erode. Analysis of daytime and night-time LST variations indicated a linear temperature increase over two decades, correlating with LULC changes. The UHI effect, particularly the change in night-time temperature, holds significant implications. Urban areas release accumulated heat slowly overnight, raising surface and ambient temperatures until the following day. Between 2013 and 2023, summer night-time temperatures increased in Thoothukkudi (0.68°C), Chennai (0.63°C), Madurai (0.36°C), and Thanjavur (0.16°C). Despite an *overall reduction in daytime surface temperatures due to decreased barren land, these areas still exhibit high surface temperatures, posing risks of prolonged thermal stress.*

The study assessed mean LST and percentage changes across 11 smart cities. In Vellore, 68% of areas are mapped under 36-40°C and 16% under 41-45°C. Since 2013, there has been a 22% increase in the 36-40°C range, with reductions of 24% and 9% in the 31-35°C and 26-30°C ranges. In Madurai, 43% and 27% of surface areas currently fall under the 36-40°C and 41-45°C ranges, with areas exceeding 45°C reduced by 17% since 2013, while those in the 36-40°C and 41-45°C ranges increased by 18% and 5%, respectively. In Salem, 43% of the area remains within the critical 41-45°C range, with a 34% and 23% increase in the 36-40°C range since 2013. Thoothukkudi's temperature distribution shows moderate (31-35°C), high (36-40°C), and critical (41-45°C) ranges at 19%, 22%, and 24%, with a 28% decrease in areas above 45°C but a 14% and 3% increase in the 36-40°C and 41-45°C ranges. Chennai, experiencing rapid urban expansion, has seen a 42% decrease in the critical temperature range (41-45°C and above) since 2003, with 64% of its area now mapped at 36-40°C.

Madurai and Thoothukkudi were chosen for detailed assessment based on population density, coastal proximity, night-time mean LST, summer LST changes, and LULC changes. Madurai, a densely populated centre, contrasts with coastal Thoothukkudi, providing a varied scope for the study. In Madurai, correlations between spectral indices and LST showed a weak, negative linear correlation between mean LST and NDVI, with Pearson correlation coefficients of R2013 = -0.155 and R2023 = -0.331, both at a 95% confidence interval. Areas with vegetation cover in 2013 displayed low NDVI values (0.1 to 0.25), and higher mean LST values (35 ± 4°C) were observed in 2023 with NDVI values rising to 0.45 to 0.6. NDBI showed a weak to moderate positive correlation with mean LST, with R2013 = 0.132 and R2023 = 0.508, suggesting a link between built-up cover and increased surface temperatures.

In Thoothukkudi, correlations indicated a weak, negative linear relationship between LST and NDVI (R2013 = -0.192; R2023 = -0.134) and a strong, positive correlation between NDBI and LST (R2013 = 0.697; R2023 = 0.635). This relationship suggests urban expansion has led to higher temperatures, with NDBI values indicating significant built-up cover and associated heat retention. Further LULC classification showed that from 2013 to 2023, Madurai lost 57 km^2 of vegetation and added 8% to built-up areas, while 4% converted to barren land. Thoothukkudi experienced a 12 km^2 increase in built-up area and a 7 km^2 decrease in open spaces.

Hotspots identified in Madurai primarily span residential, institutional, commercial, and industrial zones characterized by dense, low to medium-rise buildings, low vegetation cover, high impervious surfaces, and limited natural heat sinks. Thoothukkudi's hotspots are distributed in public, institutional, and industrial areas. Recommendations are provided for city level urban heat mitigation measures in the Chapter 4.

3. IDENTIFICATION AND ASSESSMENT OF HOTSPOTS ACROSS URBAN AREAS OF TAMIL NADU

Tamil Nadu is witnessing a notable surge in heat-stress-related discomfort as a result of urban heat and climate induced risks. According to reports, since 2014, the average number of heat-related discomfort days in 39 districts has reportedly increased by 41.5% throughout the state (Padmaja J, 2024). The state experienced 107 days of discomfort between 1985 and 2014, although on average, there will be 150 days a year with mean air temperatures over 29 °C and relative humidity levels below 30%. The cities of Thanjavur and Nagapattinam have recorded 211 days of discomfort. However, Tuticorin's discomfort days have gone up from 76 in 2014 to 152 in 2021. By 2030, 67% of the people of Tamil Nadu are expected to live in urban areas, making it the state with the highest urbanization rate. Consequently, it is also anticipated that the peak power demand would rise by 65% from 16,541 MW in 2021–2022 to 27,392 MW by 2026–2027 (Sastry, 2024). Therefore, the present study to identify the hotspots across the Tamil Nadu state, will strengthen the scientific evidence for the developing the mitigation and adaptation measures through town planning schemes or local area development plan. It will also enable the government and the other stakeholders to take necessary action against the vulnerability of UHIE.

LITERATURE REVIEW

The objective of the present study has been complied with by conducting a systematic literature review of the academic studies and pilot studies, from 2008 to 2022, to comprehend the spatio-temporal variance of UHIE over the years, the dynamics of UHIE with the urban indicators, and to identify the hotspots.

In Coimbatore, a study (Jayabharathi & Kottiswaran, 2015) found that the maximum and minimum temperature anomalies in Coimbatore had an annual increase of 0.04°C and 0.1°C, respectively. Critical temperature anomalies in Coimbatore and annual mean-maximum and minimum temperatures in Sulur and Kinattukkadavu have been attributed to the urbanization trend. Between 1995 to 2015, in Coimbatore, the built-up area increased by 11.17%, while the growth rate between 2005 to 2015 was significantly 50.04% (Saravanan et al., 2018). Consequently, the vegetation cover and water body have reduced by 14.55% and 2%, respectively. The mean land-surface temperature was observed an overall increase of 3.8°C between 2005 to 2015. Moreover, a significant increase of 1.2°C, 1.3°C, and 1.4°C was observed in dense built-up, industrial, and wastelands, respectively, during the studied period.

In Kancheepuram district, the spatial-temporal intensity of the Surface Urban Heat Island (SUHI) was mapped highest in urban and barren land. The vegetation resulted in cool sinks, where the industrial areas and paved, unshaded parking lots were identified as hotspots with the highest SUHI intensity. The LST range was observed as 25°C to 39°C in 2005, saw a significant change in 2021, and mapped as 31°C to 47°C (Raj et al., 2023). In the last four decades (1985-2021), the built-up area has increased by 20% and the mean Land Surface Temperature has increased by 152 %. The study also embarked on the transformation of land use and the thermo-physical properties of surface materials as the most critical factors of UHI.

In Tiruchirappalli, the central part is constituted with high-density urban morphology, showing higher LST. The presence of the industrial belt of BHEL and the associated township (BHEL Nagar) in the southeast part of the district contributes largely to higher UHI. According to a recent study (Badugu et al., 2023), the trend analysis also showed that the mean annual LST is rising at a rate of 0.166K per decade between 2001 to 2021. The maximum UHI intensity was mapped as 4.5 K and 4.16 K in the summer and winter for the past two decades. Night-time UHI is predominant, as the night-time maximum UHI intensity for summer mapped 5.26 K as the highest and 0.534 K as the average during summer.

District Collector office, Tiruchirappalli Railway station, Periyar Nagar, Cantonment post office, District Court, Periyar College of Pharmaceuticals, Sundaram Hospital, St. Joseph College, Airport, Shri-Raja-Rajeswari Temple area, Oxford Engineering College, and The Wireless Station, were mapped as critical hotspots. Moreover, Shri Boolaganatha Swami Temple, Thirumangalam, and Arulmiga Madhura Kaliyamman temple area were identified as heat sinks.

In Tiruppur, between 2001 and 2018, the built-up cover has increased from 21.74 sqkm to 119.02 sqkm, while the vegetation cover has reduced from 1442.3 sq. km to 1328 sq. km (Ramasamy & K., 2020). A steady increase in LST was observed during the studied period, and the estimated LST ranged between 19.32°C to 31.75 °C, where the urban built areas showed higher concentrations, but in the high-density settlements with narrow streets and taller buildings, the LST was low, however, the study mentioned that this might significantly impact the night-time UHI with higher ambient temperature. The study also embarked on the need to avoid the conversion of vegetation cover and the inclusion of appropriate urban geometry in the bylaws and urban development guidelines.

Several studies (Aarthi & Gnanappazham, 2019; Lakshmi & Thomas, 2018; Amirtham et al., 2009) (Shenbagaraj et al., 2019) have been conducted in Chennai, where Land Use Land Cover changes and Urban sprawl have been mapped through remote sensing data from 1991 to 2017, showing- a radial trend of urbanization along the major transit corridors. However, the city core already become saturated since 2013, particularly in Nungambakkam, Tondiarpet, Madhavaram, and Guindy. Urban sprawl increased at a decadal rate of 13.7% (1988-97), 6.4% (1997-2006), and 10.7% (2006-17) (M & M, 2019). Urbanization trends also projected an increase of 79.28 % by 2024 and 84.75% by 2029.

Built-up cover increased by 70% during 1991-2016 and is projected to encroach 88 % of the total land area. While waterbodies, wetlands, and dense vegetation cover have been reduced by 53.6%, 70%, and 34%, respectively. An increase in Land Surface Temperature from 31 °C to 34 °C across the peri-urban areas, which have expanded from 29.7% (1988) to 68.1% (2017), while areas with LST (more than 34 °C) have increased from 0.01% (1988) to 3.21 % (2017). Moreover, the mean LST increased by 5.8 °C during 1991-2016.

Chennai City saw an increase of 5.8 °C (from 33.34 °C to 38.92 °C) in the Land Surface Temperature (LST) from 1991 to 2016 (Chandrashekar, 2021). the heat pockets are significant in the airport, industrial (SI-DCO), commercial (T. Nagar) areas and dump yards, and cooler pockets in vegetated areas (Guindy, Pallikarani Marshland). According to the climate change projection, the ambient temperature might observe a rise from 1.6 to 2.1 °C considering the middle range and a staggering 4.1°C in 2080, according to the high end (Sánchez & Govindarajulu, 2023). Also, the critical hotspots can be summarized as Thyagaraya Nagar, Koyambedu, Mount Road, Ambattur industrial Area, Arumbakkam, Ennore, Manali, George Town, Mylapore, Perungudi, Washermenpet, Purasaiwakkam, Adayar, Airport area, Anna salai, Nungambakkam, Saidapet, Anna Nagar, Virugambakkam (Kesavan et al., 2021; Amirtham, 2016; Amirtham et al., 2009; Rajan & Amirtham, 2021) from the academic studies conducted between 2008 and 2022.

Studies (Rose A & D.Devadas, 2008; Jeganathan & Andimuthu, 2013) have also emphasized shown that the UHI variance was mapped between 2.4 °C to 3.6 °C during the summer and 3.35 °C to 4.5 °C in winter, mostly in the central and northern parts configured by densely populated residential areas, commercial nodes (T. Nagar), and industrial areas. Also, the thermal stress (THI) is projected to increase by 5°C during peak summer (May, June) and 4.1°C in winter (November, December) by this century's end (Jeganathan et al., 2019). However, the western and southwestern parts of the CMA are identified as the most critical areas.

Urban microclimate studies in this regard, have identified that the east-west oriented streets with deeper canyons results in higher Tmrt (mean radiant temperature, an indicator of outdoor thermal comfort). However, the study also showed that the low sky view factor, high-density settlements resulted in low day-time Temperature and high night-time Temperature (Rajan & Amirtham, 2021). The studies mentioned that the open spaces and playgrounds result in higher daytime thermal stress. However, large canopy trees produce Physiological Equivalent Temperature (PET) with similar SVF. The study (Horrison & Amirtham, 2016) have also concluded that with modification in the neighbourhood configuration (as amended in Tamil Nadu Combiner Development and Building Rules, 2019) by optimizing the SVF, pervious cover, and conversion of plot setback with green cover, the simulation showed positive results towards enhancing outdoor thermal comfort (reduction in MRT, PET) during the peak summer in May, from 10:10 to 17:00 hrs. Tmrt and low SVF is also concluded as critical in reducing PET (Salal Rajan & Amirtham, 2021).

OBJECTIVE OF THE STUDY

The objective of this study is identification and assessment of hotspots across the urban areas of Tamil Nadu and to provide recommendations for managing UHIE mitigation and adaptation focusing on designated Smart Cities of the state.

3.1 APPROACH AND METHODOLOGY

In this chapter, the approach considered for data collection and mapping, analysis, and validation of the results will be discussed. The methodology is developed to achieve the objective of identification and assessment of hotspots across urban areas of Tamil Nadu and recommendations for managing UHIE mitigation focusing on designated Smart Cities of the state.

3.1.1 DATA COLLECTION

REMOTE SENSING DATA

The datasets from remote sensing will enable the acquisition of spatio-temporal changes in Land Use Land Cover (LULC) and Land Surface Temperature (LST) at a predefined resolution in a single snapshot. Following remote sensing datasets were collected for this analysis, as illustrated in Figure-33

- Yearly Temporal data of MODIS (aqua and terra sensors) Land Surface Temperature retrieved at 1km pixels for the years 2003, 2013 and 2023 for daytime and night-time.

- Monthly Temporal data of MODIS (aqua and terra sensors) Land Surface Temperature retrieved at 1km pixels for the years 2003, 2013 and 2023 for daytime and night-time.

- Landsat8 (TIRS bands) satellite data having a spatial resolution of 30 meters for the year of 2013 and 2023.

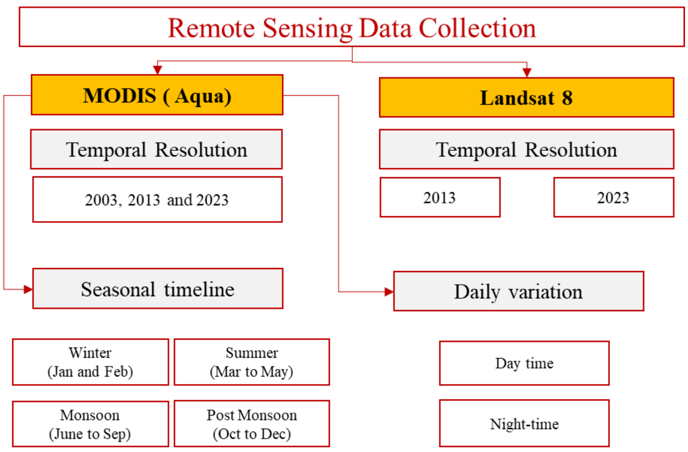


Figure 33: Remote Sensing datasets and source

SPATIAL ADMINISTRATIVE DATA

Spatial Administrative data refers to location-based data demarking any boundary or parcel at an administrative level. Following remote sensing datasets, as illustrated in Figure-34 were collected for this analysis-

- Tamil Nadu State Boundary
- Tamil Nadu District Boundary
- Smart Cities Boundary

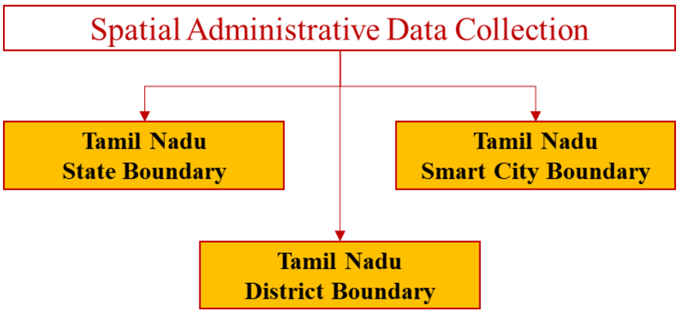


Figure 34: Spatial Administrative Datasets and source

3.1.2 METHODOLOGY

Initial phase of the research involved systematic literature review focusing on surface and canopy level heat island, and its association with Land Use Land Cover changes and built environment indicators across the Tamil Nadu State and its smart cities, in particular. From this literature review, major trends patterns and key findings such as hotspots and their spatio-temporal UHIE variability were documented.

Based on the literature, smart cities of the Tamil Nadu state were considered for the further assessment. To identify the trends in Land Surface Temperature (LST) for 2003, 2013 and 2023 in Tamil Nadu, mean daytime and night-time LST data were obtained along with the smart city boundaries of the state. The data was then categorized into four seasons and then summer season data was used for the analysis. The LST data was further extracted and clipped for the smart city boundary. And based on the mean LST values, the temperature range was defined and assigned to the data. Finally based on the obtained output, mean daytime and night-time seasonal LST trends were prepared, and a detailed analysis was done for the smart cities. The methodology for the mapping and assessment is shown in the Figure-35.

Simultaneously, Land Use Land Cover (LULC) classification was done. Landsat 8 satellite data was acquired for the classification of smart cities for 2013 and 2023. The data was classified into four classes namely waterbodies, open space/barren land, built-up and vegetation. Based on the classification, the variability and changes within each class for the years 2013 and 2023 was assessed across all the smart cities of Tamil Nadu state. Eleven smart cities within the state of Tamil Nadu were selected to undergo a comprehensive analysis of their LST and comprehending the literature review.

Out of the eleven smart cities, two smart cities were screened for an in-depth assessment based on population density, proximity to coast, spatio-temporal variance of night-time mean LST and percentage change in area coverage with respect to mean LST. Also, correlation was identified with LULC and Landscape metrics (NDBI, NDVI and MNDWI) for selected smart cities.

The CARBSE, CRDF team have already done a comprehensive analysis of the UHIE and its associated indicators, along with the current govt. policies, pilots, initiatives, in their ongoing study for Chennai Metropolitan Area. Therefore, to avoid the repetition, Chennai was not included in this present study.

Following the comprehensive analysis (as illustrated in Figure-36) of the selected two smart cities, hotspots within the cities were identified where high LSTs prevailed. Finally, recommendations for mitigating UHIE, were provided based for the identified hotspots, based on the representative land use.

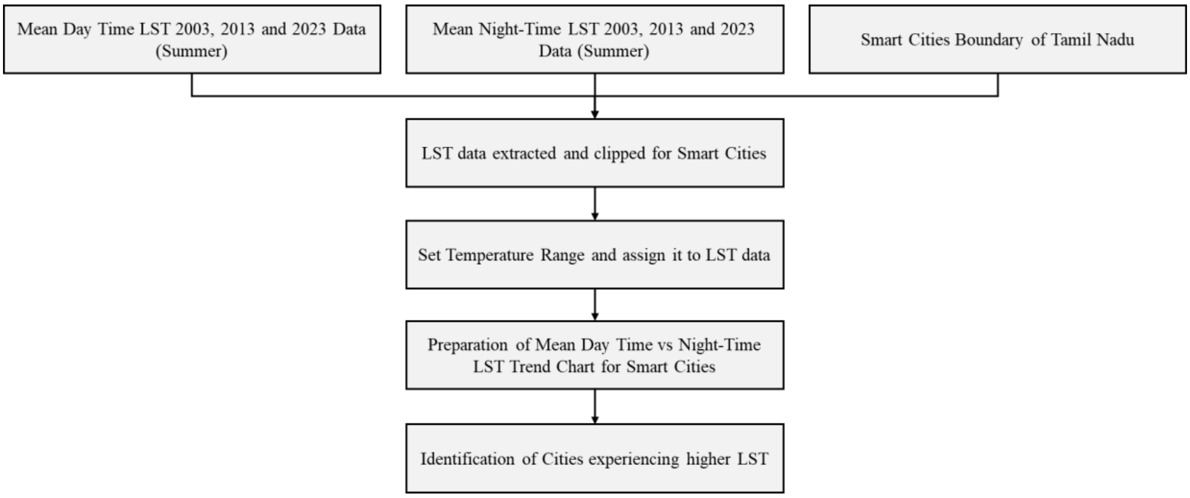


Figure 35: Trend Analysis of LST for years 2003, 2013 and 2023 Methodology

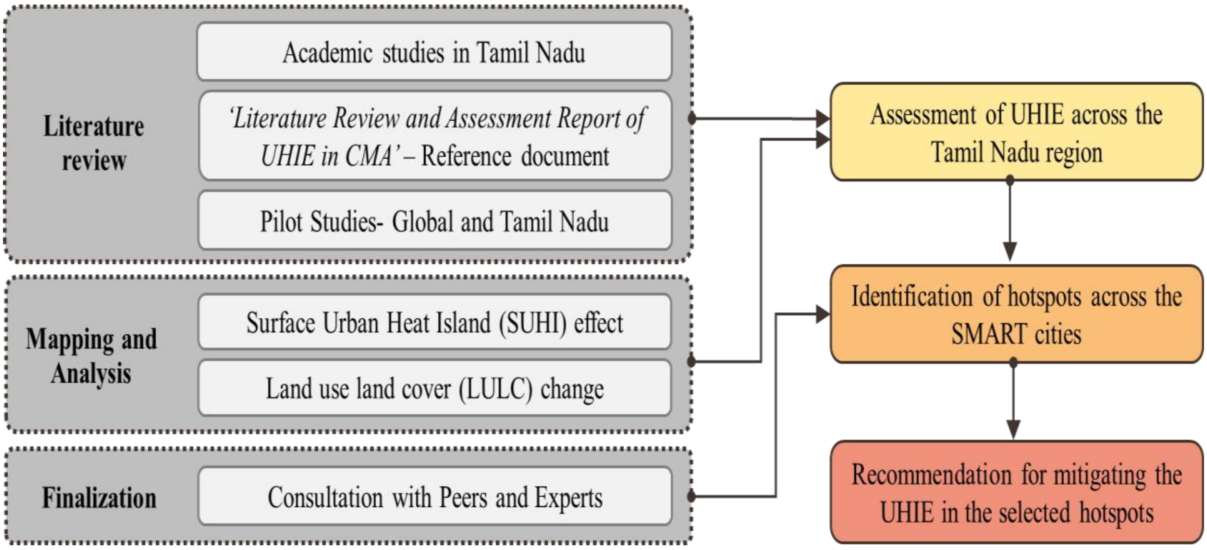


Figure 36: Overall Analysis Workflow

3.2 COMPREHENSIVE ANALYSIS OF SMART CITY

This section discusses about smart cities of Tamil Nadu and the need to identify day and night-time variances in LST of the smart city as a comparative study followed by identifying percentage of area coverage coming under maximum/high LST zones.

3.2.1 SMART CITIES OF TAMIL NADU STATE

Why are smart cities prioritized for UHIE studies ?

Smart Cities must address the Urban Heat Island Effect to mitigate rising temperatures caused by rapid urbanization. This is crucial for improving urban livability, reducing energy demand, tackling health risks, managing water stress, enhancing climate resilience, and integrating Nature-Based Solutions for sustainable planning and development aligned with global climate and urban goals

'Smart Cities Mission' was launched by Government of India in the year 2015 with an objective of promoting the cities which can provide clean and sustainable environment, core infrastructure and decent standard of living.

Eleven cities (see Figure-37) were identified for implementing smart solutions and top-notch infrastructure with world class amenities.

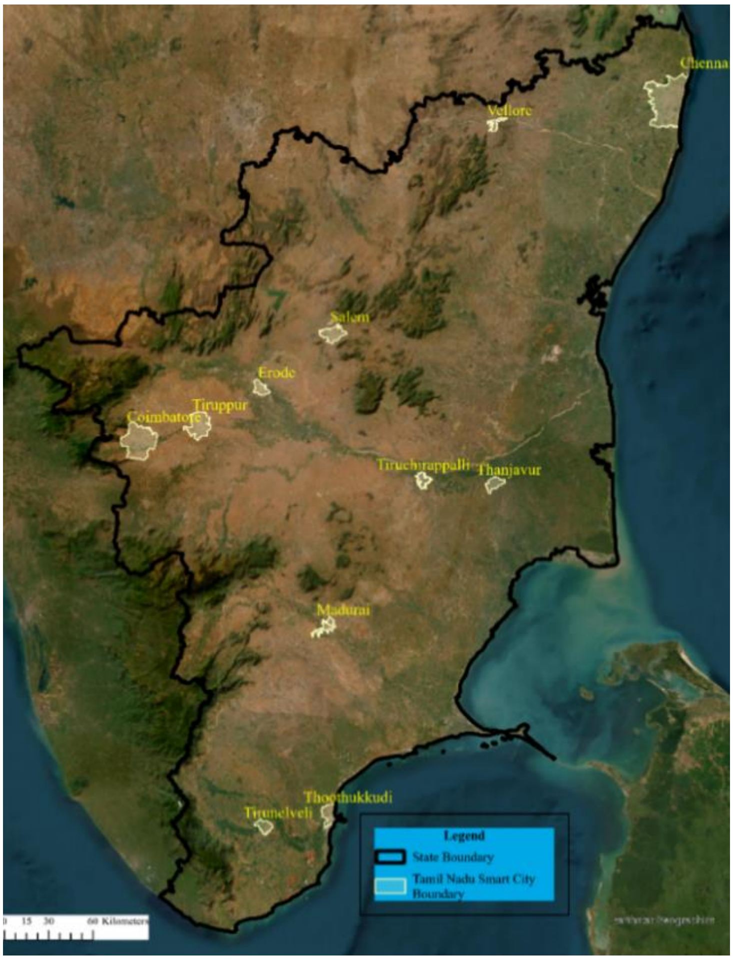


Figure 37: . Smart Cities of Tamil Nadu

They are Chennai, Coimbatore, Madurai, Salem, Thanjavur, Vellore, Tuticorin (Thoothukudi), Tirunelveli, Tiruppur, Tiruchirappalli and Erode.

3.2.2 ASSESSMENT OF DAYTIME AND NIGHT-TIME VARIABILITY OF LST

To identify the spatio-temporal variances in LST of daytime and night-time, mean LST data for the years of 2003, 2013 and 2023 were considered. Summer (from March to May) was adopted for identifying the heat stress for Tamil Nadu state due to extreme temperatures experienced in summers.

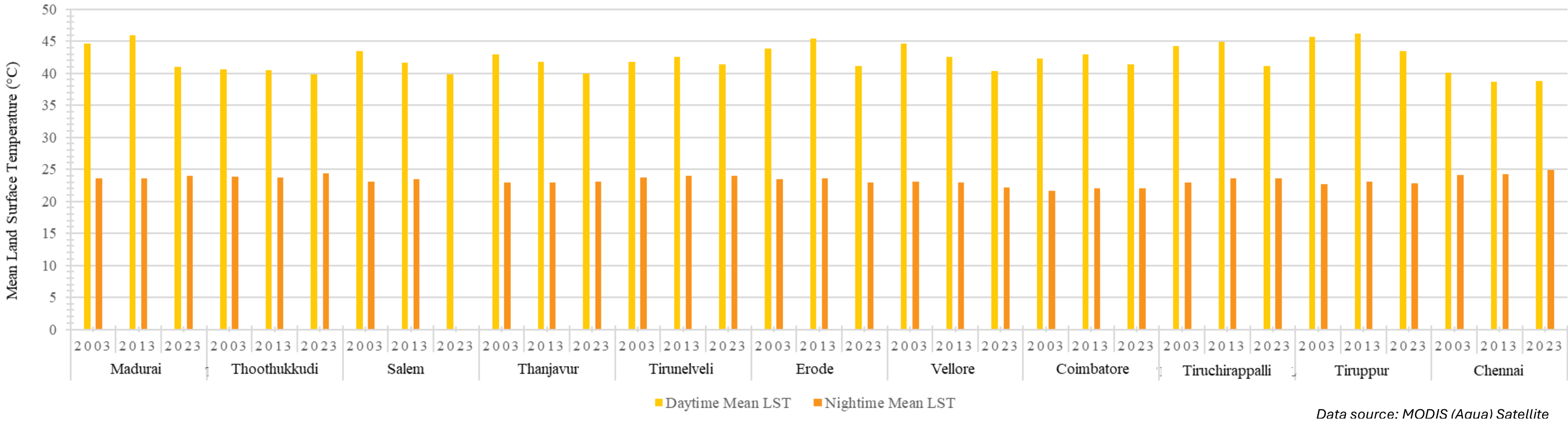


Figure 38: Daytime and Night-time Variances of LST Chart ((source: MODIS (Aqua) Satellite))

Note: Due to the cloud cover and the limitation of the dataset, the night-time surface temperature of 2023 for Salem could not be documented.

As evident from the Figure-38, notable trend of decreasing mean daytime temperatures during summer has been observed for majority of the smart cities of the state. On the other hand, there is a clear increase in summer mean night-time temperature observed in various smart cities across Tamil Nadu including Thoothukkudi (0.68°C), Chennai (0.63°C), Madurai (0.36°C), and Thanjavur (0.16°C) from 2013 to 2023. Despite a reduction in overall daytime temperatures, which attributed due to the decrease in barren land over the studied period, it still exhibits the highest temperature trend. The transformation of barren lands into built cover over the past decades is contributing to the retention of heat during the daytime, which is subsequently released at night under the cool sky and thus resulting in increase of night-time temperatures. This phenomenon aggravates the risks of outdoor thermal stress with high humidity across the hotspots.

3.2.3 ANALYSIS OF MEAN SUMMER LST AND PERCENTAGE OF AREA COVERAGE

Land Surface Temperature (LST) data was categorized into various temperature ranges to assess temperature trends of summer across the Tamil Nadu state. By identifying areas (%) falling within the maximum temperature range, significant trends in LST changes were obtained for 2003, 2013 and 2023

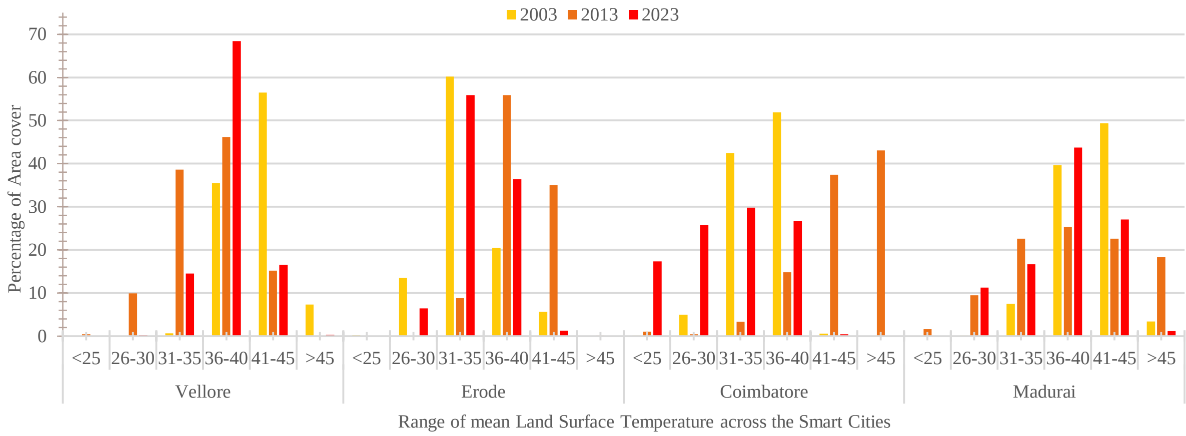


Figure 39: Percentage of area coverage – 1 (Source: Landsat satellite)

In Vellore, presently the larger coverage (i.e., 68% and 16%) is mapped under the range of 36°C to 40°C and 41°C to 45°C. However, over the past decade (since 2013) significant changes were observed in areas which increased by 22 % under the temperature range of 36°C to 40°C and reduced by 24%, 9% under the temperature range of 31°C to 35°C, and 26°C to 30°C, respectively.

In Erode, almost 56% and 36% of total geographic area are mapped across the temperature range of 31°C to 35 °C and 36°C to 40°C, respectively. However, areas under the critical temperature range of 36°C to 40°C and 41°C to 45°C, have reduced considerably by 19% and 34%, since 2013.

In Coimbatore, significant changes were observed where the areas under the critical temperature range of 41°C to 45°C and over 45°C, were reduced by 37% and 43%, respectively since 2013. And presently the areas are closely distributed across the temperature range of 26°C to 40°C, in 2023.

At present, almost 43% and 27% of total surface areas of Madurai, lies under the temp. range of 36°C to 40°C and 41°C to 45 °C, respectively. Moreover, areas with critical temperature of above 45°C, have reduced by 17% since 2013, but areas under the temperature range of 36°C to 40°C and 41°C to 45°C have increased by 18% and 5% since the last decade.

In Salem and Thanjavur, larger surface cover mapped across the temperature range of 31°C to 35°C and 36°C to 40°C, respectively in 2023. However, in Salem 43% area under the critical temperature range of 41°C to 45°C have been reduced since 2013. While in both cities, areas under the high temperature range of 36°C to 40°C have increased by 34% and 23% since 2013.

Since 2013, in Tirunelveli the areas under the critical temp. range of 41°C to 45°C and above 45°C have reduced by 13% and 11%, respectively. However, at present the areas under the high (i.e., 35°C to 40 °C) and critical (i.e., 41°C to 45°C) temperature range, still have the larger distribution of land cover, almost as 42 and 35%, respectively.

Since the last decade in Tiruppur, areas under the critical temperature range of 41°C to 45°C and above 45°C have reduced significantly by 52% and 22.5%. And presently the areas under the temperature range of 31°C to 35°C and 36°C to 40°C comprise of the larger distribution as 32% and 67%, respectively.

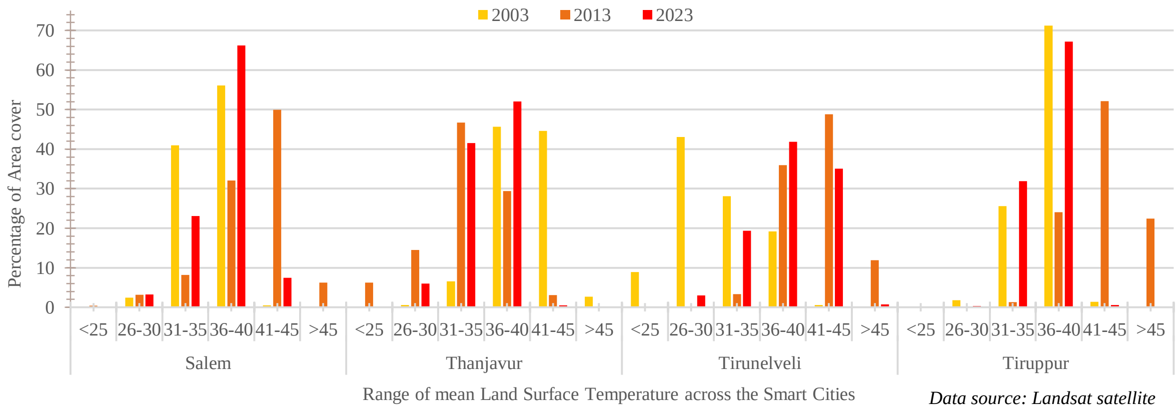


Figure 40: Percentage of area coverage – 2 (Source: Landsat satellite)

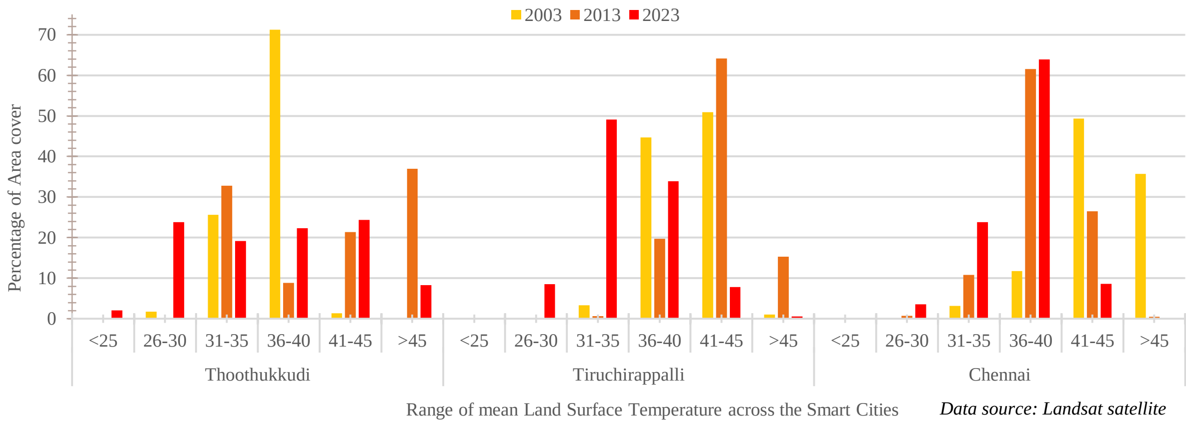


Figure 41: Percentage of area coverage - 3

At present in Thoothukkudi, the areas under the moderate (31°C to 35 °C), high (36°C to 40 °C) and critical (41°C to 45°C) temperature range distributed closely as 19%, 22%, and 24%. Since 2013, the areas under the critical temp. range (above 45°C) have reduced significantly by 28%. However, areas under the temperature range of 36°C to 40 °C and 41°C to 45°C have increased by 14% and 3%, respectively in the last decade.

In Tiruchirappalli, areas under the critical temp. range of 41°C to 45°C and above 45°C, have reduced drastically by 57% and 15% since 2013. Presently, the dominant area cover is distributed as 49% and 34% across the temperature range of 31°C to 35°C and 36°C to 40°C. And areas under the critical temperature range of 41°C to 45°C and above 45°C is mapped as low as 8 and 0.6%, respectively.

Over the decade, Chennai has observed a rapid urban expansion, and presently it has become saturated. In Chennai (i.e., the largest urban agglomeration of Tamil Nadu), the largest area cover (64%) have mapped across the high temp. range of 36°C to 40°C in 2023. However, areas under the critical temperature range (e.g., 41°C to 45°C and above 45°C) range have reduced by 42% to 35% since 2003.

3.3 DETAILED ANALYSIS OF SMART CITIES

The parameters used to select two smart cities from eleven across the state is discussed in this section. Additionally, the influence of landscape metrics and identify hotspots, focusing on areas experiencing high LST is also explained. Eleven smart cities within the state of Tamil Nadu have been selected to undergo a comprehensive analysis of their Land Surface Temperature and to identify hotspots. Out of the eleven smart cities, few smart cities are considered based on specific parameters including population density, proximity to coast, spatio-temporal variance of night-time mean LST and percentage change in area coverage with respect to mean LST.

3.3.1 PARAMETERS FOR SELECTION OF 2 CITIES

Based on certain indicators and parameters, two smart cities of Tamil Nadu have been selected for analysing trends of night-time LST and identifying hotspots having maximum temperatures during night-time. The parameters for screening considered are-

i) Population Density,
ii) Proximity to Coast,
iii) Night-time mean LST and
iv) Percentage change in area coverage with respect to mean LST which are mentioned in the following sub-sections.

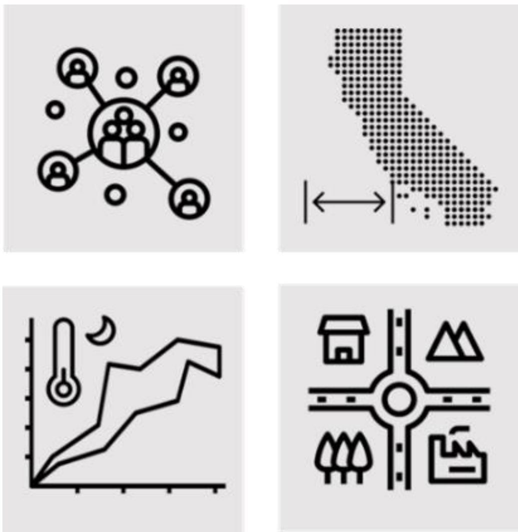


Figure 42: Parameters considered

POPULATION DENSITY

Population density means number of individuals per unit geographic area (for e.g., number per m^2, per ha, or per km^2) (Schowalter, 2006).. Considering the population density as a key criterion, cities with the highest population densities were evaluated to visualize the impact of LST on densely populated cities and identify the correlation between population density and LST of densely populated cities.

Based on Census data as shown in Table 1, the population density is highest for Chennai city followed by Madurai, Salem and Thoothukudi.

Table 1. Population Density of Smart Cities of Tamil Nadu (Population Census 2011 India, 2011)

City/Agglomeration	Spatial coverage (sq.km)	Total Population	Population Density
Chennai	789.00	8,653,521	10,972
Coimbatore	642.00	2,136,916	3,328
Madurai	143.00	1,465,625	10,248
Salem	115.00	917,414	7,960
Thanjavur	74.30	291,067	3,917
Vellore	141.00	488,690	3,446
Thoothukudi	63.70	411,628	6,466
Tirunelveli	135.00	497,826	3,681
Tiruppur	198.00	963,173	4,870
Tiruchirappalli	199.00	1,022,518	5,150
Erode	130.00	521,891	4,000

PROXIMITY TO COAST

Proximity to coast is highly important under large population and socio-economic vulnerability due to increase heat stress under anthropogenic global warming (Rehnberg, 2021). Large variabilities in coastal stations are reported compared to inland stations in terms of surface temperature (Maddu et al., 2021). Cities near to coast were given priority to identify the correlation between coastal areas and Land Surface Temperature. Cities such as Chennai and Thoothukudi are nearest to the coast. Thus, are given high priority as compared to other smart cities of the state as evitable from the Figure-37.

SPATIO-TEMPORAL VARIANCE OF NIGHT-TIME MEAN LST

Spatio-Temporal variance of Night-time LST provides valuable insights to identify the changes in LST over the time period. Night-time mean LST data for the summer months (for two years 2013 and 2023) were considered for this analysis.

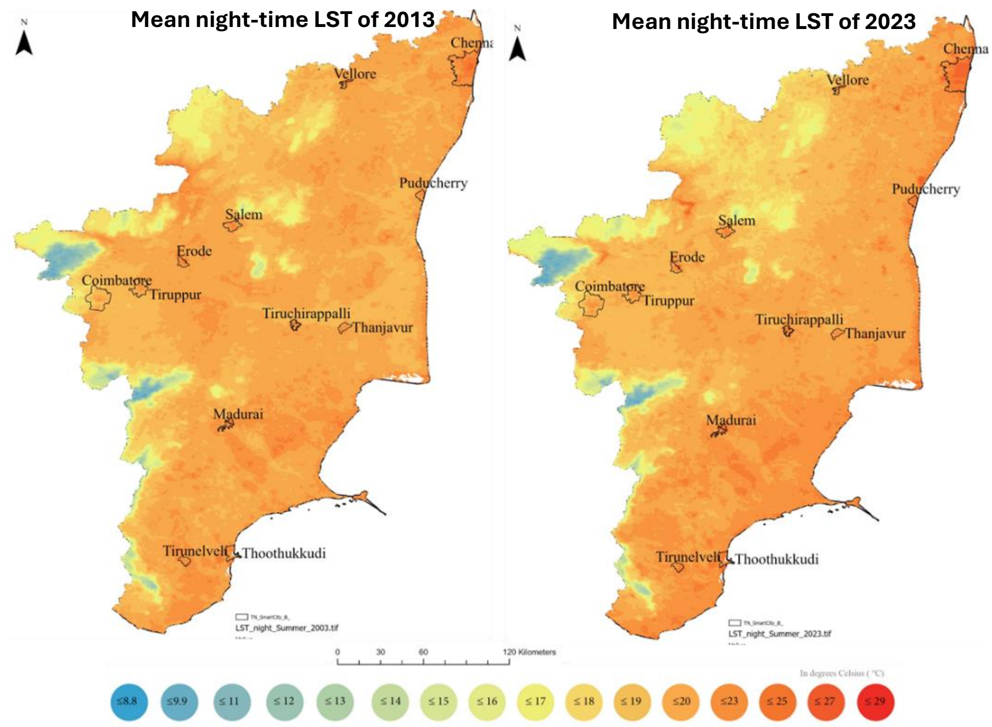


Figure 43: Night-time LST for the summer months ((MODIS (Aqua) Satellite))

As observed from the night-time LST maps in -44, there is a significant increase in summer mean night-time temperature observed in various smart cities across Tamil Nadu including Thoothukkudi (0.68°C), Chennai (0.63°C), Madurai (0.36°C), and Thanjavur (0.16°C) from 2013 to 2023. Thus, these cities are given priority over other cities of the state.

PERCENTAGE CHANGE IN AREA COVERAGE

Based on the percentage change, smart cities that showed notable variations in area coverage with reference to mean LST in summer were identified and selected. Based on the analysis as discussed in section 3.2.3 Analysis of mean summer LST and percentage of area coverage" of this document, Chennai, Madurai and Thoothukudi showed significant change in area coverage having temperature ranges over 36°C. Thus, give priority over other smart cities of the state.

Considering crucial parameters including population density, proximity to coast, spatio-temporal variance of night-time mean LST and percentage change in area coverage with respect to mean LST, Chennai, Madurai, and Thoothukudi emerged as the selected cities for identification of hotspots in these cities. A buffer zone extending approximately 5 kms from the city boundary was taken to consider the LST of sparse settlements on the outskirts of the city. Buffer of about 8 km around the city limits were taken to also consider the LST of sparse settlements in the outskirts of the city.

Note- Separate study has been conducted for the Chennai city and CMD area, the analysis is focused solely on Madurai and Thoothukudi for identification of hotspots in these cities, as mentioned earlier.

3.3.2 ASSESSMENT OF UHIE IN MADURAI

- Madurai City, situated in South Central part of the state, ranks as second largest corporation city after Chennai and stands as the third largest city by population.
- According to the Census of 2011, the Madurai Corporation has a population of 1,470,755 people.
- Characterized by hot and dry weather for eight months of the year, Madurai experiences cold winds from December to March. The peak of summer (March to July) witnesses temperatures reaching 40 °C and a minimum of 26.3 °C, with occurrences of temperature over 42 °C is not uncommon. During Winter months, temperatures range between 29.6 °C and 18 °C (TNPCB, 2021).
- An area of 686 km^2 is considered for the analysis purpose as displayed in
- Figure - 44 which includes Madurai city boundary and an 8 km buffer surrounding the limits for considering the evident outskirts settlements.

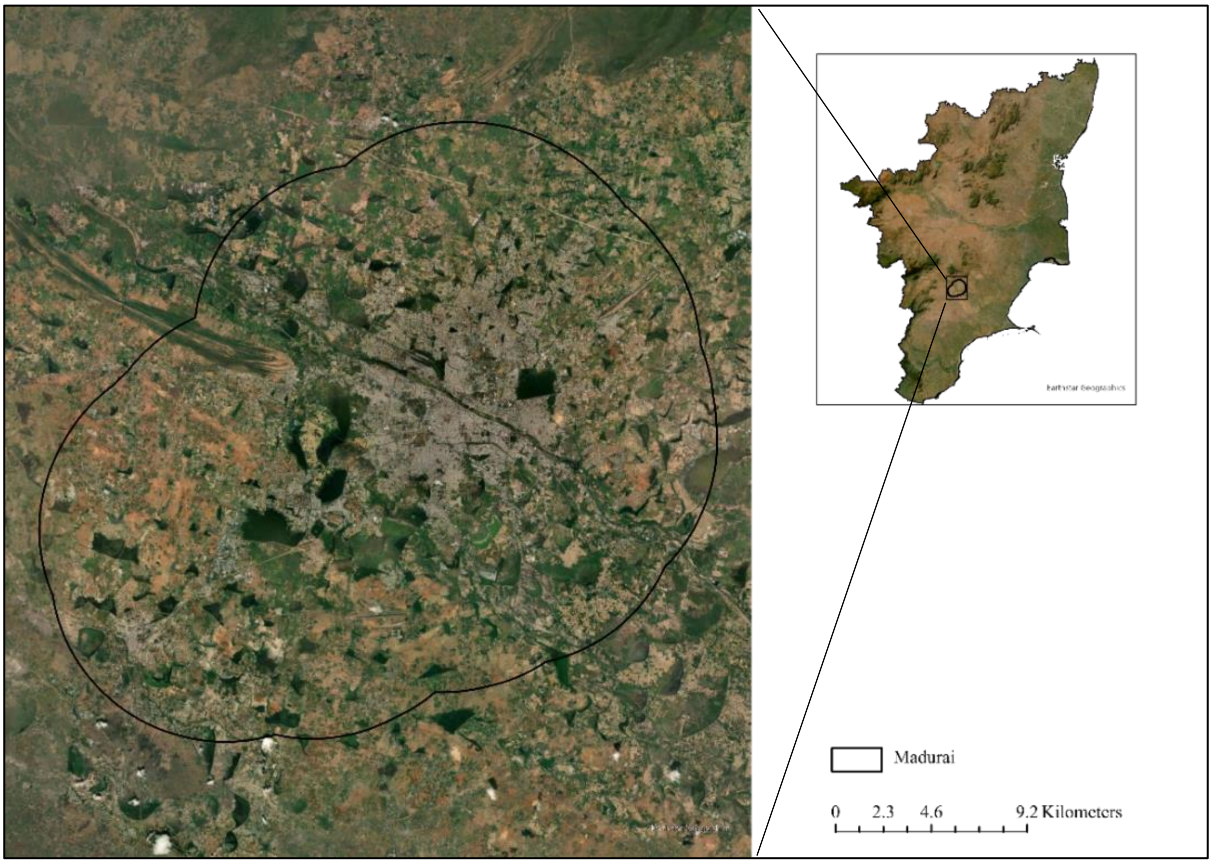


Figure 44: Madurai city boundary with buffer

To identify the impact of landscape metrics on Land Surface Temperature in Madurai, various indicators including NDVI, MNDWI and NDBI were analysed. The impact of LST in relation to these metrics were analysed to identify any correlation of LST with these metrics.

3.3.2.A IMPACT OF LANDSCAPE METRICS ON LST IN MADURAI: NDVI

The results, as evitable from Figure-45 and Figure-46, displays a weak, negative linear correlation exists between mean LST (summer) and NDVI with Pearson correlation coefficient values of R_{2013}= -0.155 for 2013 and R_{2023}= -0.331 for 2023, respectively, and all at a 95% confidence interval. The results also showed that the higher values of mean surface temperature during the summer were recorded between 45 to 50 °C, especially where the vegetation cover (e.g., forest, shrub land) is particularly low (NDVI ~ 0.1 to 0.25) in 2013.

However, there has been an increase in NDVI values from 0.45 to 0.6 over the decade. In those areas, the higher values of mean LST were mapped between 35 ± 4 °C in 2023.

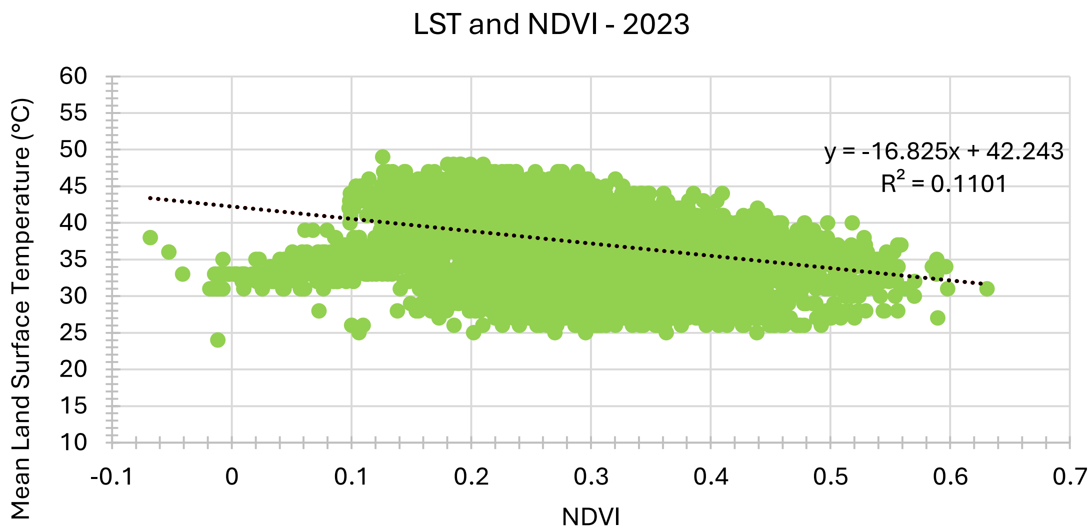


Figure 45: Correlation of LST and NDVI 2023 for Madurai

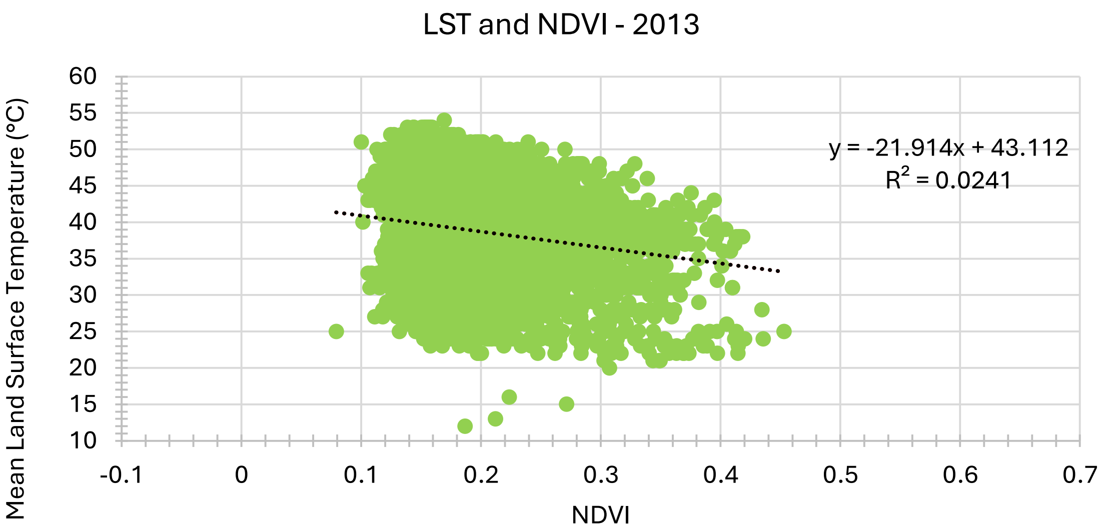


Figure 46: Correlation of LST and NDVI 2013 for Madurai

3.3.2.B IMPACT OF LANDSCAPE METRICS ON LST IN MADURAI: MNDWI

The results, as evitable from Figure-47 and Figure-48, displays a weak, negative linear correlation between mean LST (summer) and MNDWI with Pearson correlation coefficient values of R_{2013}= -0.228 for 2013 and R_{2023}= -0.0616 for 2023, respectively, and all at a 95% confidence interval. The results also showed that the higher values of mean surface temperature during the summer were recorded between 45 to 50 °C, especially where the water index is particularly negative or low (MNDWI ~ -0.2 to 0) in 2013.

Moreover, there has been an increase in MNDWI values from 0.2 to 0.4 over the decade. In those areas, the higher values of mean LST were mapped around 35 ± 2 °C in 2023.

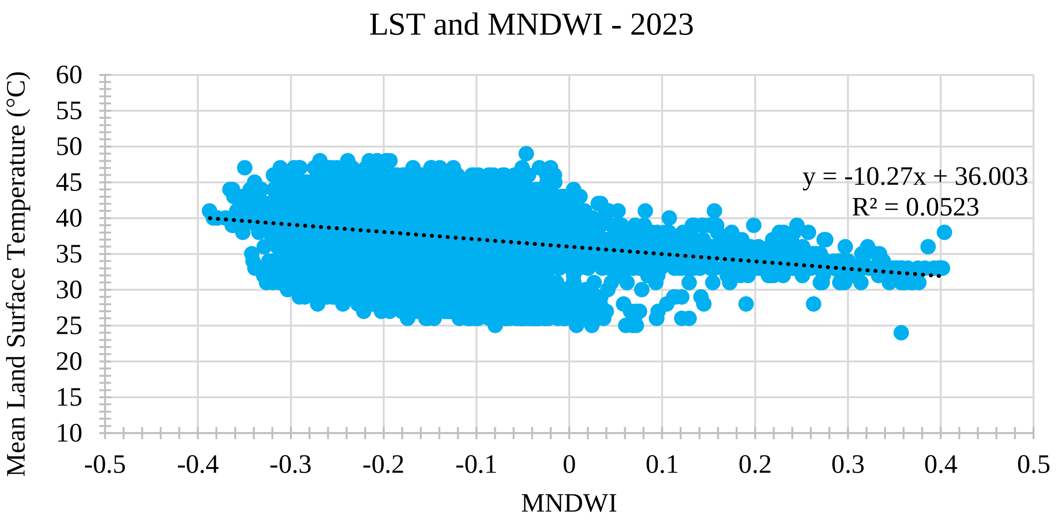


Figure 47: Correlation of LST and MNDWI 2023 for Madurai

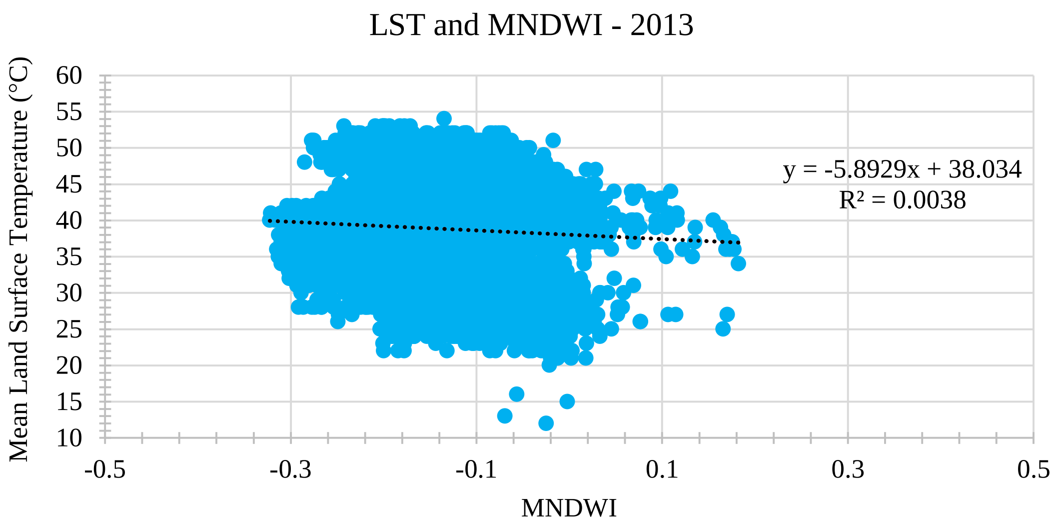


Figure 48: Correlation of LST and MNDWI 2013 for Madurai

3.3.2.C IMPACT OF LANDSCAPE METRICS ON LST IN MADURAI: NDBI

The results, as evitable from Figure-49 and Figure-50, displays a weak to moderate, linear positive correlation between mean LST (summer) and NDBI with Pearson correlation coefficient values of R_{2013}= 0.132 for 2013 and R_{2023}= 0.508 for 2023, respectively, and all at a 95% confidence interval. The results also showed that the higher values of mean surface temperature during the summer were recorded between 50 to 55 °C, especially where the built-up cover is particularly high (NDBI ~ -0.1 to 0), and the presence of vegetation was low in 2013.

However, there has been a small increase in NDBI values from 0.05 to 0.1 over the decade. And the upper limit of mean LST was mapped around 45 ± 2 °C in 2023.

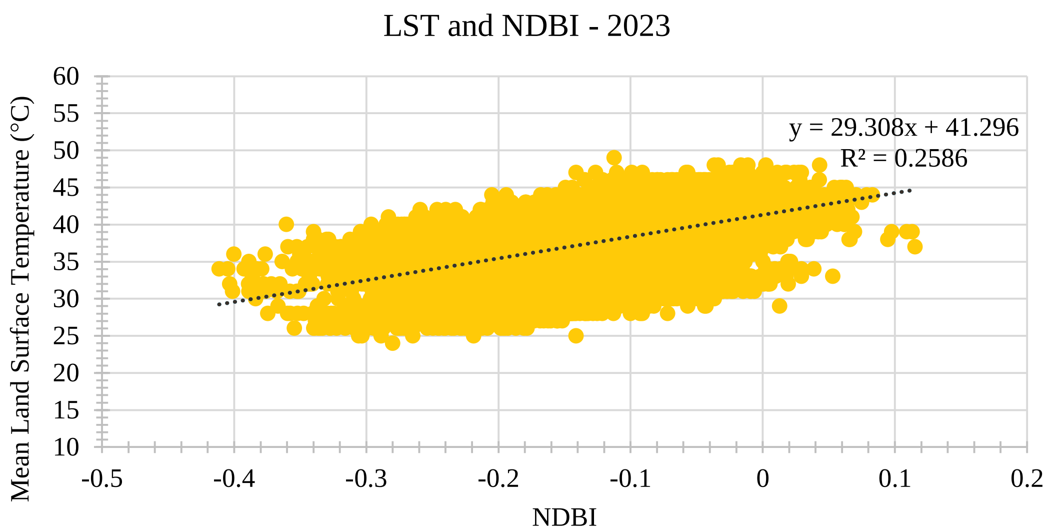


Figure 49: Correlation of LST and NDBI 2023 for Madurai

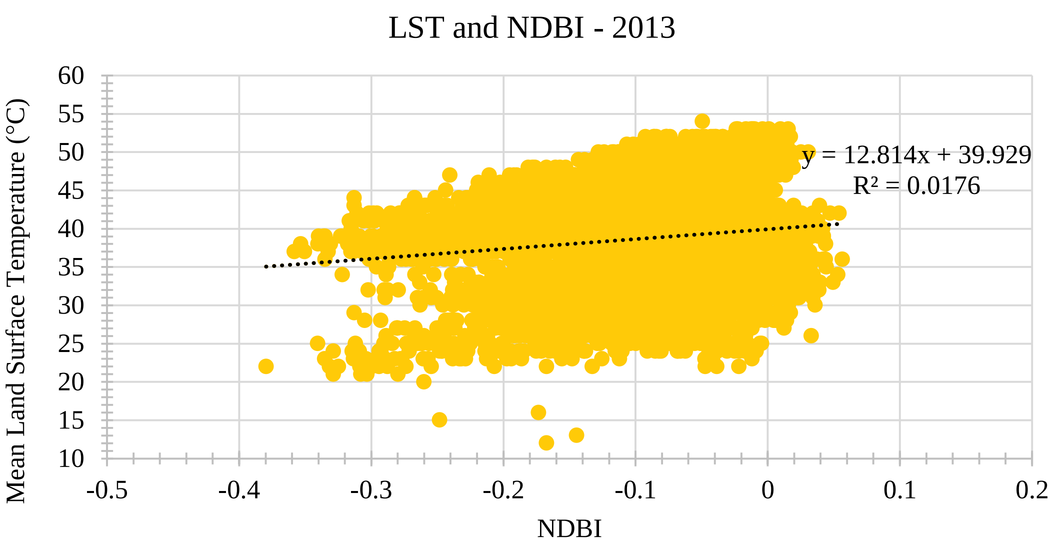


Figure 50: Correlation of LST and NDBI 2013 for Madurai

3.3.2.D LULC CHANGE FROM 2013 TO 2023

Land-use classification is used for describing both land use as well as land cover (LULC) significantly (Cabral et al., 2016). LULC classification and change detection is useful for policymakers to understand environmental changes thus ensuring sustainable development (Kennedy et al., 2018). Therefore, classification of LULC in different classes is important (Cabral et al., 2016). For classification purpose, Landsat imagery for the year 2013 and 2023 was acquired and LULC classification was done for the Madurai city with 4 classes namely waterbodies, open space/barren land, built-up and Vegetation.

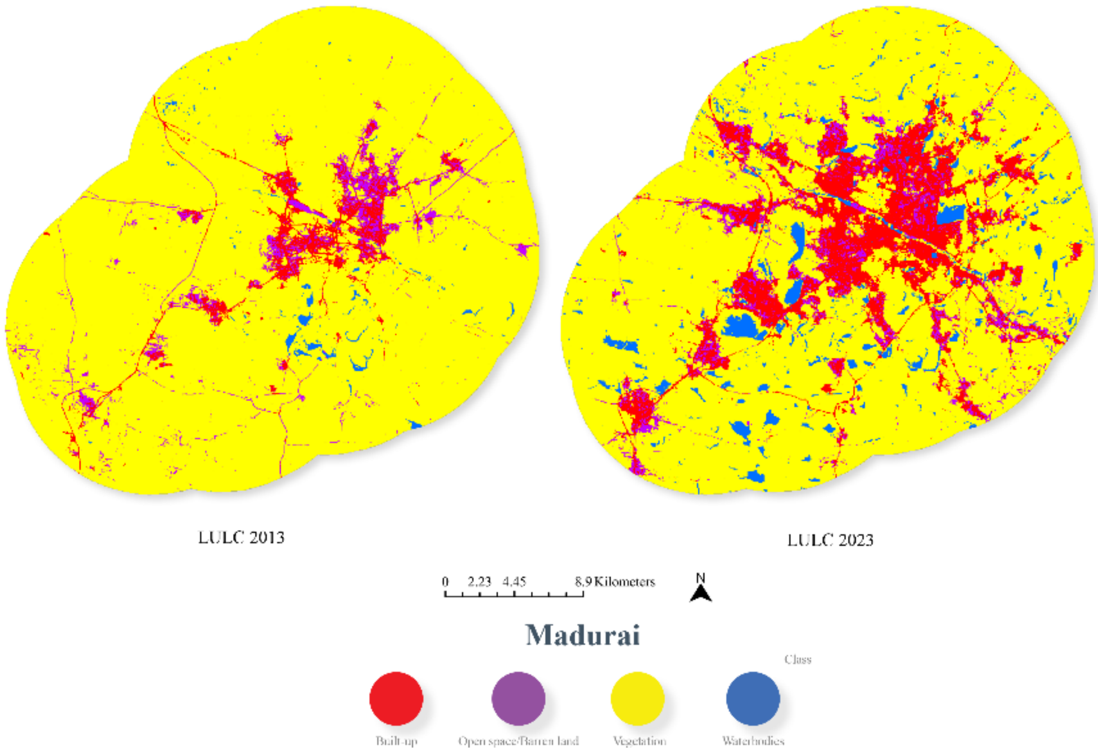


Figure 51: D LULC CHANGE FROM 2013 TO 2023

As depicted from the Figure - 51, there has been a significant increase in built-up area in the centre of the city. Urbanization has increased by three folds may be due to population migration towards the city area. Small pockets of urban settlement are also visible in the outskirts of the city. Between 2013 to 2023, 57 km^2 of vegetation area has converted to built-up area which accounts 8% of land use transformation, while 28 km^2 area has transformed to barren land which accounts for 4% transformation. Overall, in the last decade, there has been a notable LULC transformation across Madurai City.

3.3.2.E SELECTED HOTSPOTS ACROSS MADURAI

Based on the derived LST maps, various hotspots across the city were identified having higher LST values. Only a few hotspots across the city have been considered, as shown in Figure-52, with the assumption that the same mitigation strategies and recommendations would be applicable to other hotspots of the city.

The hotspots are mapped across the designated residential, institutional, commercial, and industrial pockets. They are mostly characterized by –

- hyperdense, low to medium-rise settlements with low sky view factor, high paved areas, barren/wasteland with low tree cover, and
- absence of natural heat sinks (large open space, waterbody, green cover), permeable surface cover, high anthropogenic heat emission, etc.

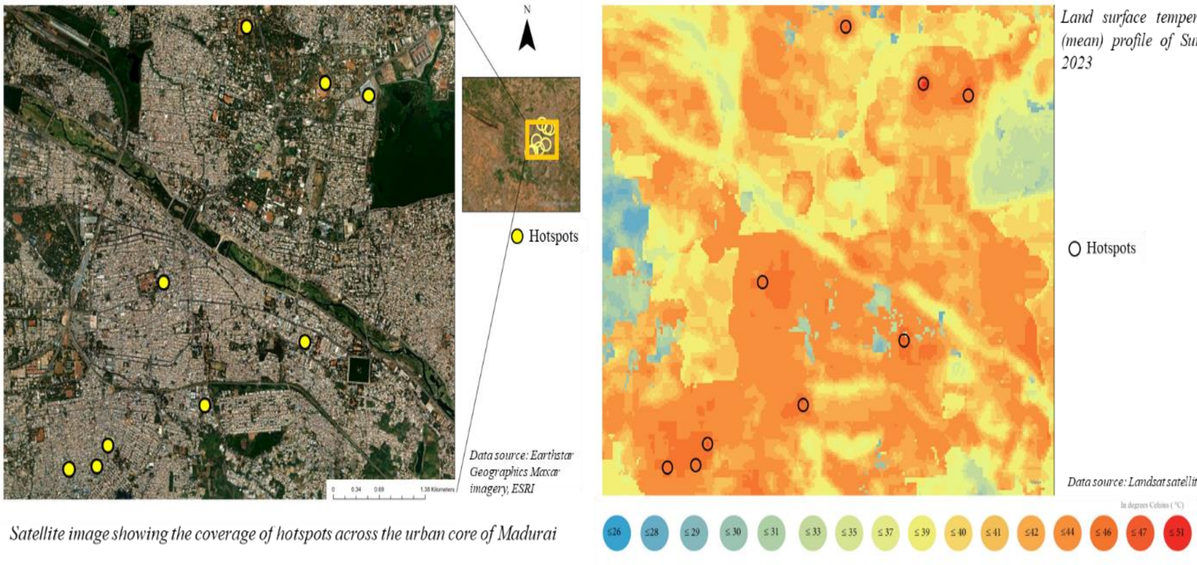


Figure 52: Hotspots across Madurai City

3.3.2.F RECOMMENDATION FOR UHIE MITIGATION FOR MADURAI

Designated land use (common)	Area Description	Increase of Green Cover	Change of Surface cover	Restoration of adjacent natural Heat sinks	Sustainable transportation	Climate sensitive Urban morphology	Green roof	Envelope optimization	Building energy efficiency
Type 1: Institutional	Densely spaced buildings with low sky view factor; large conventional roof cover and paved walkways; unshaded open spaces with sparse vegetation and situated along the major transit corridor.	Mandatory	Mandatory	Important	Good to have	Important	Important	Mandatory	Mandatory
Type 2: Industrial	Large unshaded paved areas and barren grounds; high anthropogenic heat emission; metal sheet roofing; absence of vegetation and adjacent to a major transit corridor.	Mandatory	Mandatory	Important	Good to have	Not required	Not required	Mandatory	Mandatory
Type 3: Commercial	High density settlement with low sky view factor; presence of large conventional roof and paved areas; absence of vegetation; distant proximity to natural heat sinks and situated along the major transit corridor.	Mandatory	Mandatory	Important	Good to have	Mandatory	Important	Mandatory	Mandatory
Type 4: Residential	Hyper-dense, low to midrise settlement with conventional roof; high paved areas, absence of green pockets; distant proximity to natural heat sinks and conventional envelope material with low albedo.	Mandatory	Mandatory	Important	Good to have	Mandatory	Good to have	Mandatory	Mandatory

Not required | Good to have | Important | Mandatory

Figure 53: Recommendations for UHIE Mitigation: Madurai

3.3.3 ASSESSMENT OF UHIE IN THOOTHUKUDI

- Thoothukudi city is situated in the extreme south-eastern corner of the Tamil Nadu state. The city experiences a typical climate with high humidity and relatively lower to moderate temperatures throughout the year. The annual mean minimum and maximum temperatures are 23.7°C and 33.9°C. May is the hottest month of the year with an average temperature of 31.6°C, while January has milder temperature with an average of 26.5°C.
- An area of 318 km^2 is considered for the analysis purpose which includes Thoothukudi city boundary and a 5 km buffer surrounding the limits as shown in Figure-54.

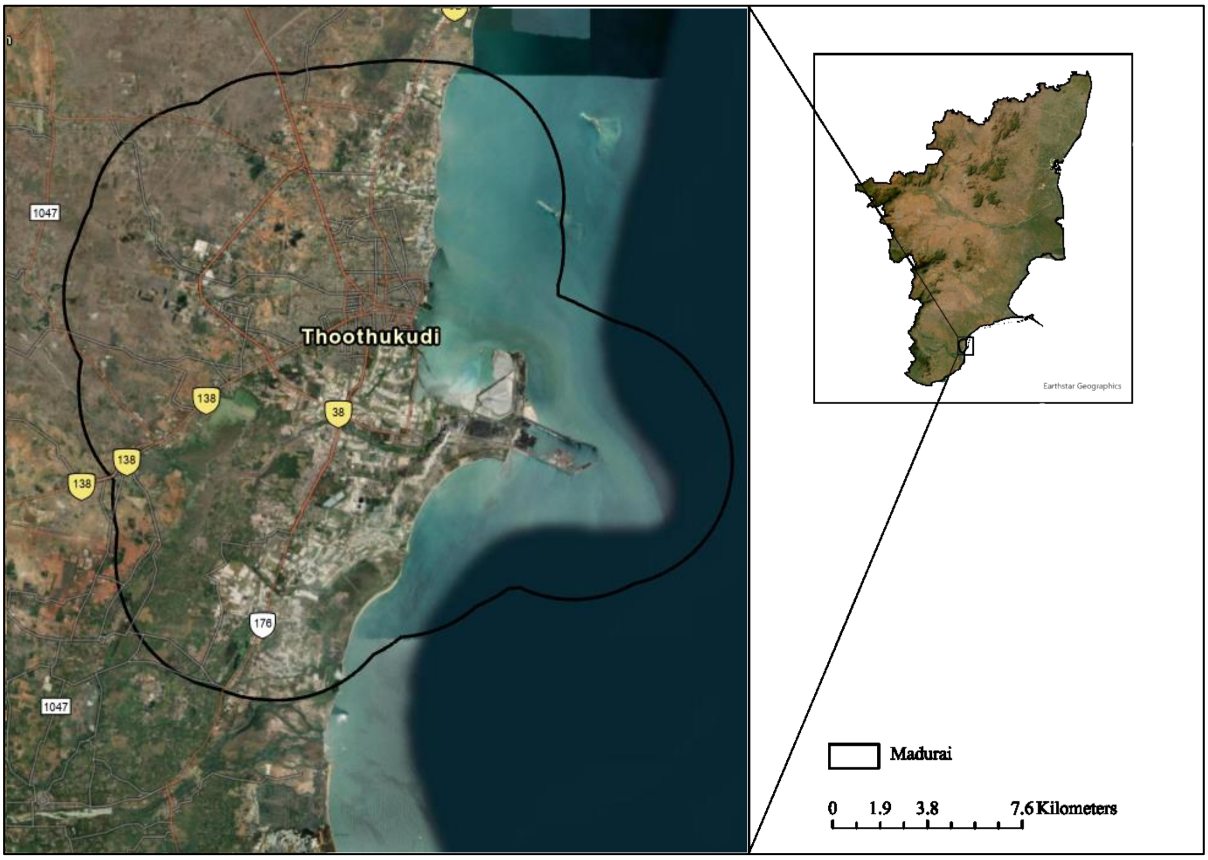


Figure 54: Thoothukudi city boundary with buffer

To identify the impact of landscape metrics on Land Surface Temperature in Thoothukudi, various indicators including NDVI, MNDWI and NDBI were analysed. The impact of LST in relation to these metrics were analysed to identify any correlation of LST with these metrics.

3.3.3.A. IMPACT OF LANDSCAPE METRICS ON LST IN THOOTHUKUDI: NDVI

The result, as evitable from Figure-55 and Figure , shows a weak, negative linear correlation between mean LST (summer) and NDVI with Pearson correlation coefficient values of R_{2013}= -0.192 for 2013 and R_{2023}= -0.134 for 2023, respectively, and all at a 95% confidence interval.

The results also showed that the upper limit of mean surface temperature during the summer was recorded between 50 to 55 °C, where the vegetation cover was particularly low (NDVI ~ 0.1 to 0.2) as compared to areas with higher vegetation cover (NDVI ~ 0.5 to 0.6). However, the upper limit of mean LST value mapped around 35 ± 4 °C, in 2023.

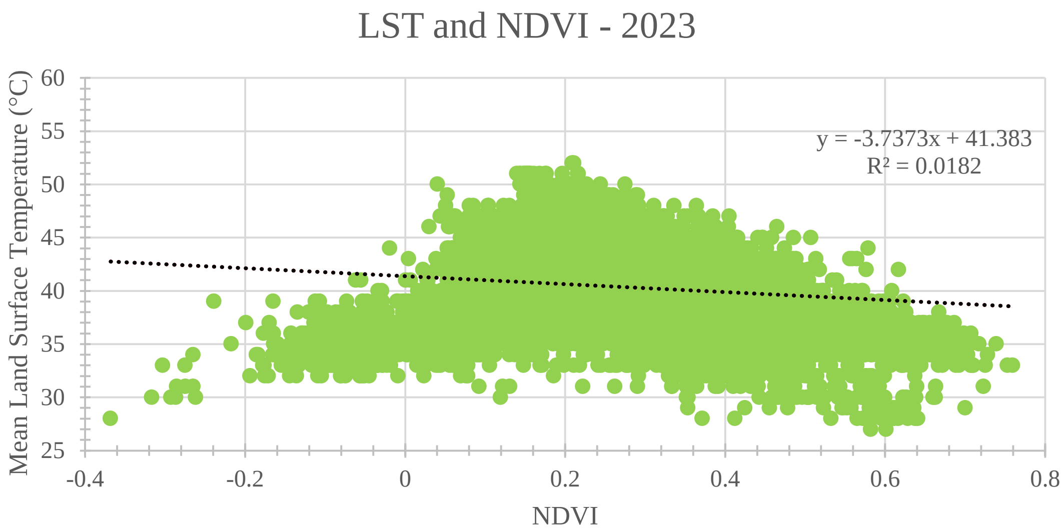


Figure 55: Correlation of LST and NDVI 2023 for Thoothukudi

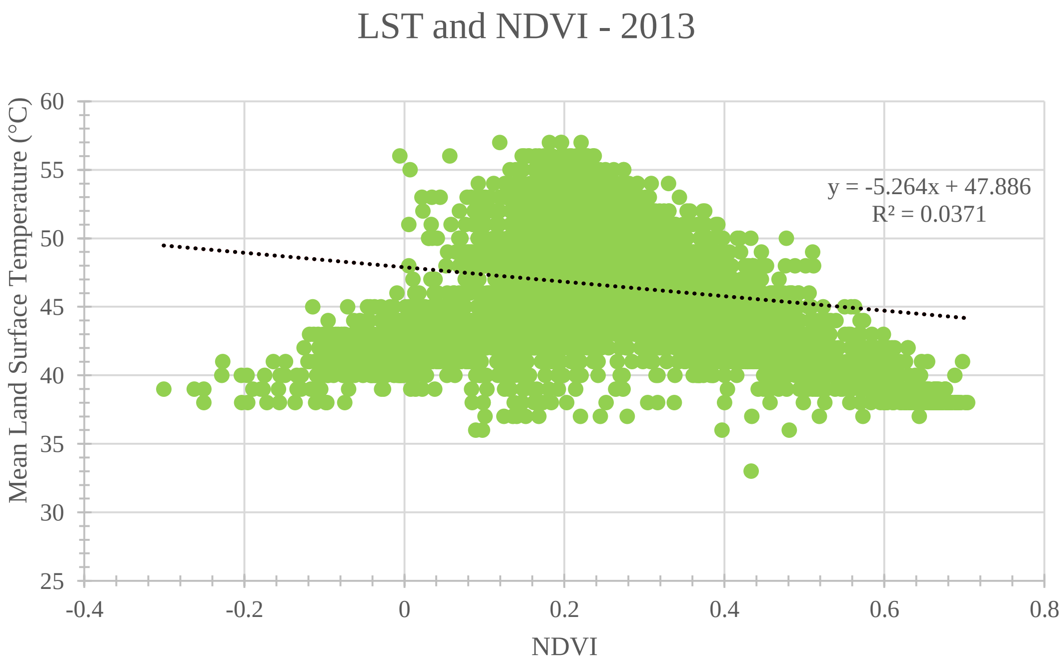


Figure 56: Correlation of LST and NDVI 2013 for Thoothukudi

3.3.3.B. IMPACT OF LANDSCAPE METRICS ON LST IN THOOTHUKUDI: MNDWI

The result, as evitable from Figure-57 and Figure , shows a moderate, negative linear correlation between mean LST (summer) and MNDWI with Pearson correlation coefficient values of R_{2013}= -0.470 for 2013 and R_{2023}= -0.412 for 2023, respectively, and all at a 95% confidence interval.

The results also showed that the upper limits of mean surface temperature during the summer were mapped between 50 to 55 °C, especially where the water index is particularly negative or low (MNDWI ~ -0.4 to -0.2) in 2013. However, the upper limit of mean LST value mapped between 45 to 50 °C in 2023 in similar areas (MNDWI ~ -0.2 to 0).

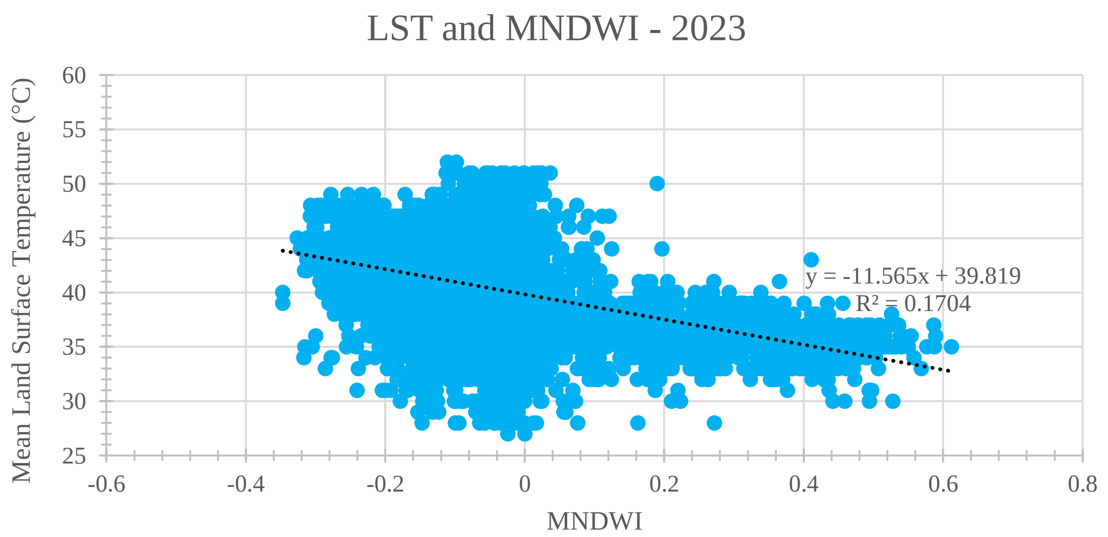


Figure 57: Correlation of LST and MNDWI 2023 for Thoothukudi

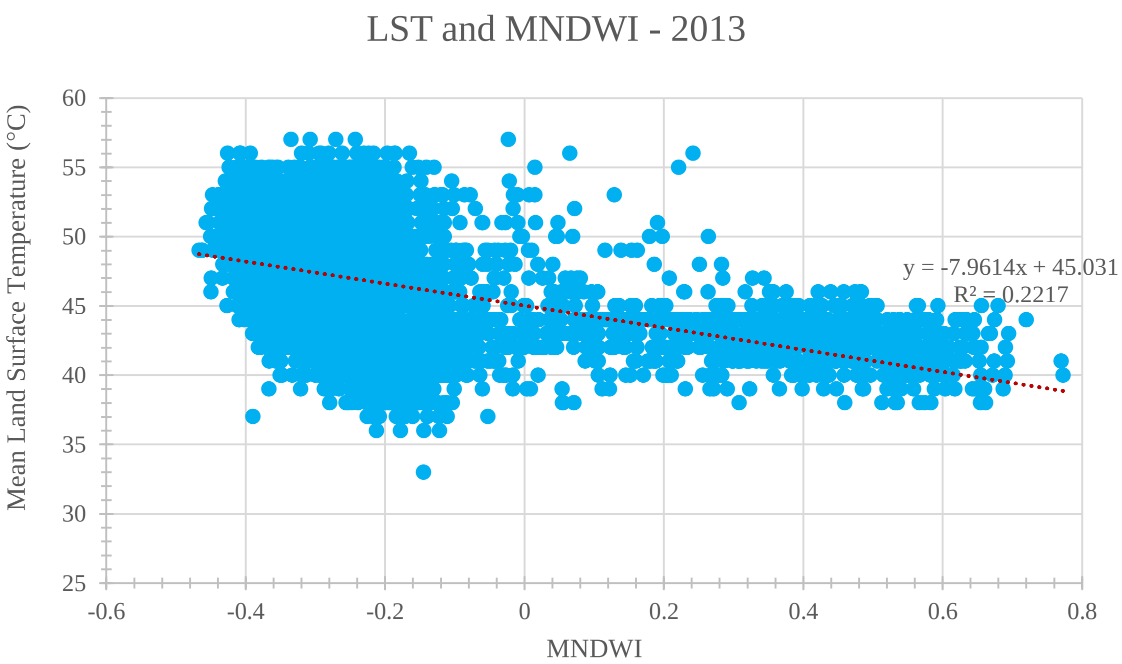


Figure 58: Correlation of LST and MNDWI 2013 for Thoothukudi

3.3.3.C. IMPACT OF LANDSCAPE METRICS ON LST IN THOOTHUKUDI: NDBI

The result, as evitable from Figure-59 and Figure-60, shows a strong, linear positive correlation between mean LST (summer) and NDBI with Pearson correlation coefficient values of R_{2013}= 0.697 for 2013 and R_{2023}= 0.635 for 2023, respectively, and all at a 95% confidence interval.

It implies that the presence of a built-up area has an impact on the LST (summer) at a particular spot. From the observations, it is observed that due to urban sprawl, an increase in built-up cover or density (NDBI ~ -0.05 to 0.1) led to an increase in mean surface temperature (e.g., the upper limit mapped in the range between 50 to 55 °C), particularly in 2013.

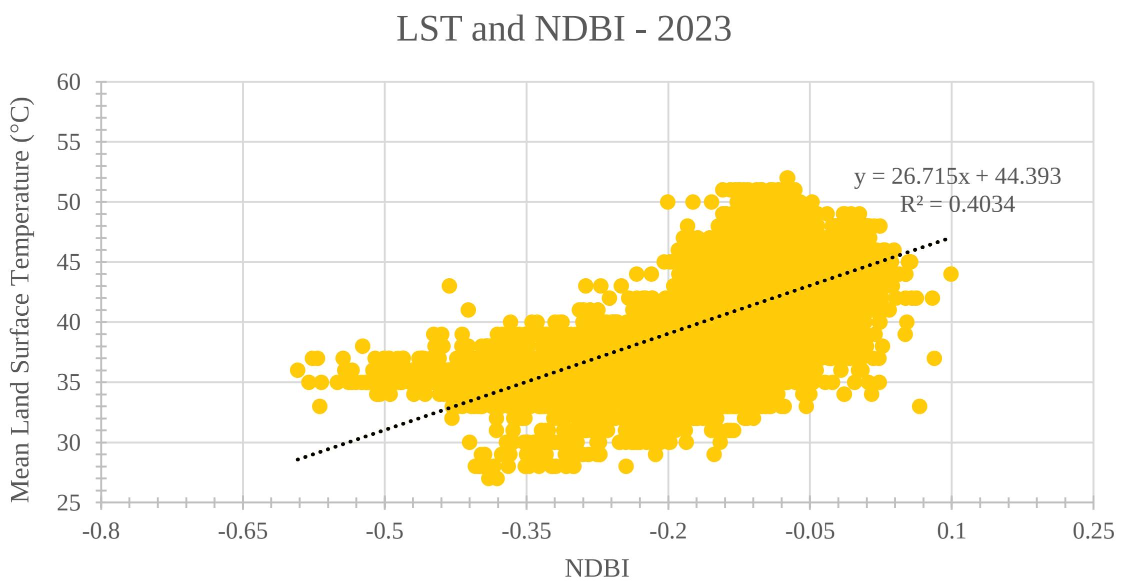


Figure 59: Correlation of LST and NDBI 2023 for Thoothukudi

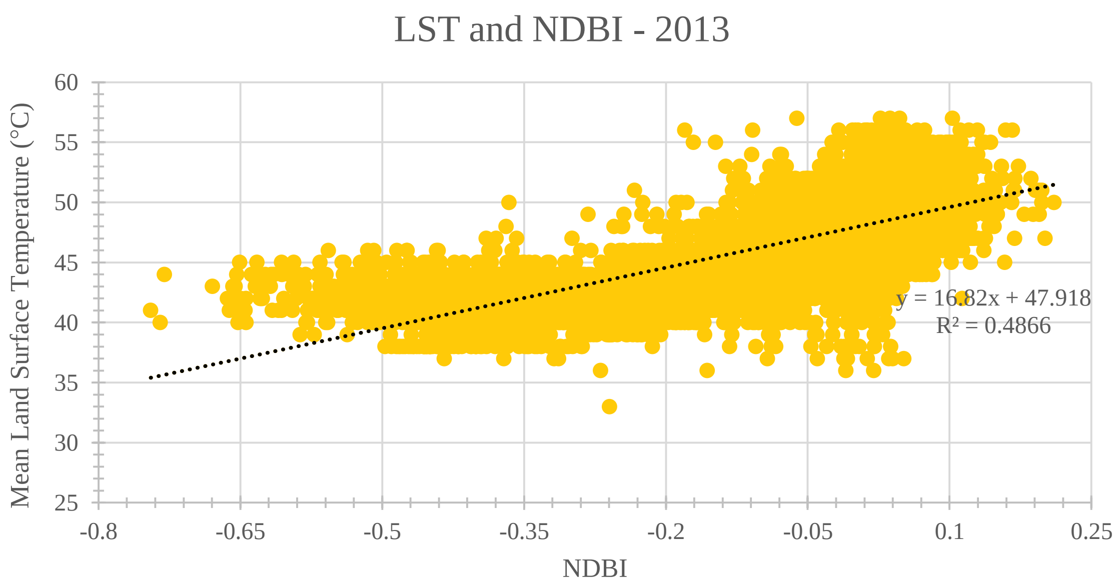


Figure 60: Correlation of LST and NDBI 2013 for Thoothukudi

3.3.3.D. LULC CHANGE FROM 2013 TO 2023

Land-use classification is used for describing both land use as well as land cover (LULC) significantly (Cabral et al., 2016). LULC classification and change detection is useful for policymakers to understand environmental changes thus ensuring sustainable development (Kennedy et al., 2018). Therefore, classification of LULC in different classes is important (Cabral et al., 2016). For classification purpose, Landsat imagery for the year 2013 and 2023 was acquired and LULC classification was done for the Thoothukudi city with 4 classes namely waterbodies, open space/barren land, built-up and Vegetation.

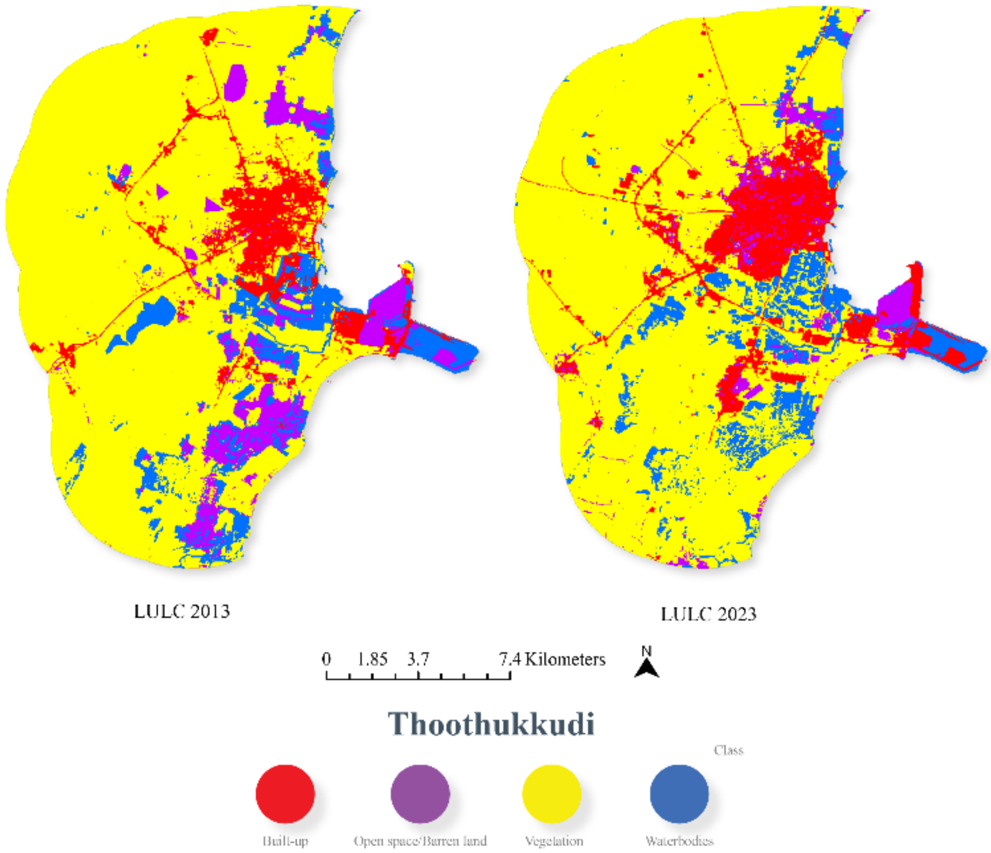


Figure 61: LULC Classification 2013 -2023

As depicted from the Figure-61, there has been a significant increase in built-up area around city area. Urbanization has increased primarily by two folds may be due to population migration towards the city area. Small pockets of urban settlement are also visible in the outskirts of the city. Between 2013 to 2023, there has been an increase in built-up area of 12 km^2 and a decrease in open space by 7 km^2. Overall, in the last decade, there has been a notable LULC transformation across Thoothukudi City.

3.3.3.E. SELECTED HOTSPOTS ACROSS THOOTHUKUDI

Based on the derived LST maps, various hotspots across the city were identified having higher LST values as shown in Figure-62 . Only a few hotspots across the city have been considered, with the assumption that the same mitigation strategies and recommendations would be applicable to other hotspots of the city.

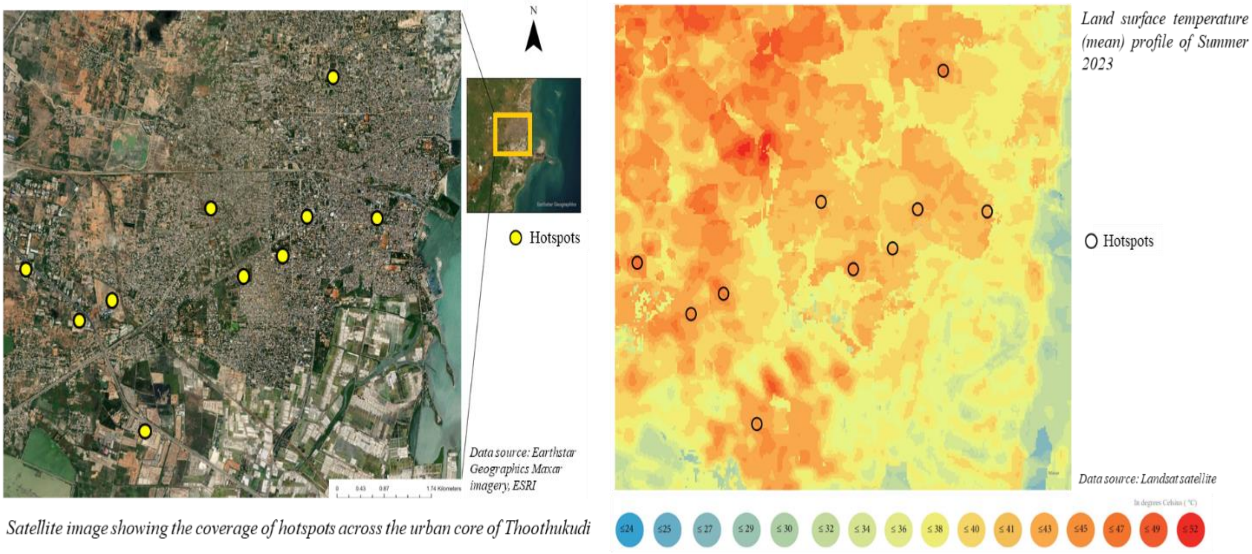


Figure 62: Hotspots across Thoothukudi City

The hotspots are mapped across the designated public and semi-public, institutional, and industrial pockets. They are mostly characterized by –

- hyperdense, low to medium-rise settlements with low sky view factor, high paved areas, barren/wasteland with low tree cover, and
- absence of natural heat sinks (large open space, waterbody, green cover), permeable surface cover, high anthropogenic heat emission, etc.

3.3.3.F. RECOMMENDATION FOR UHIE MITIGATION FOR THOOTHUKUDI

Designated land use (common)	Area Description	Increase of Green Cover	Change of Surface cover	Restoration of Natural Heat sinks	Sustainable transportation	Climate sensitive Urban morphology	Green roof	Envelope optimization	Building energy efficiency
Type 1: Public and Semi public	Large unshaded, paved open spaces; low vegetation cover; high anthropogenic heat emission; large conventional roof coverage; adjacent to a transit corridor.	Mandatory	Mandatory	Important	Good to have	Important	Important	Mandatory	Mandatory
Type 2: Industrial	Large paved areas and barren grounds; high anthropogenic heat emission; metal sheet roofing; adjacent to a major transit corridor; absence of vegetation.	Mandatory	Mandatory	Important	Good to have	Not required	Not required	Mandatory	Mandatory
Type 3: Institutional	Densely spaced buildings with low sky view factor; presence of large conventional roof, large unshaded open space; adjacent to a major transit corridor.	Mandatory	Mandatory	Important	Good to have	Important	Important	Mandatory	Mandatory

Not required | Good to have | Important | Mandatory

Figure 63: Recommendations for UHIE Mitigation: Thoothukudi

CHAPTER 4

RECOMMENDATIONS FOR URBAN HEAT ISLAND EFFECT MITIGATION & ADAPTATION

4. RECOMMENDATIONS FOR UHIE MITIGATION AND ADAPTATION

This chapter presents strategic recommendations to mitigate the Urban Heat Island Effect (UHIE) in Tamil Nadu through interventions at the state, city, and building levels. Given Tamil Nadu's hot and humid climate, especially in densely urbanized areas like Chennai, Madurai, and Coimbatore, a comprehensive approach combining surface-level UHIE assessments with microclimate evaluations is essential. These combined assessments will equip urban planners and policymakers with data-driven insights to make sustainable, long-term decisions, particularly as rising temperatures and climate change intensify urban heat challenges. The Chennai Metropolitan Development Authority (CMDA) is already incorporating such measures into the Chennai Master Plan 2026. Similar approaches are recommended for regional, master, and local area plans across the State, focusing on building resilient and adaptive urban systems.

Under the Tamil Nadu Heat Mitigation Strategy (TN HMS), these recommendations target not only human needs but also the broader ecosystem, addressing the effects of extreme heat on plants, animals, and natural resources. This chapter includes guidance for mitigating health impacts related to excessive heat and provides solutions focused on cooling and sustained productivity for both urban and rural areas.

The strategy document is designed to extend beyond the initial project phase, guiding individual departments on actionable steps for lasting impact. Local heat resilience projects often fail due to gaps in integration, finance, and strategic planning—factors critical to ensuring long-term project viability. By offering a pathway to move key recommendations to the Detailed Project Report (DPR) stage, the strategy document supports in identifying areas for pilot implementation and potential state-wide rollout. It highlights existing policies and schemes that departments can leverage to enhance heat resilience. The TNSPC and TNSDMA will function as knowledge hubs for advancing heat mitigation by offering technical support, capacity-building, and assistance in project management, regulatory compliance, financing, and stakeholder engagement. They will also provide guidance on gender, social equity, and inclusion considerations across departments.

4.1 STATE LEVEL RECOMMENDATIONS

The Heat Mitigation Strategy identifies six leading agencies as anchors for immediate heat mitigation efforts across key sectors (refer to Table 2 for details on agency roles) at the State Level. To foster systemic climate-proofing in Tamil Nadu, this document directs stakeholders toward prioritizing actionable, resilient strategies. Drawing on case studies and identifying practical opportunities, it outlines pathways for sustainable development and climate resilience, strengthening the foundation for protecting people, nature, and infrastructure in a warming climate. The guiding principles to deliberate further on state level action plan for urban heat mitigation is also provided in this section following Table 2.

Table 2. Leading Agencies for Heat Mitigation Efforts

1.	**Revenue and Disaster Management**	• Tamil Nadu Disaster Risk Reduction Agency (TNDRRA) • Commissionerate of Revenue Administration and Disaster Management
2.	**Environment, Climate Change, and Forests**	• Department of Environment and Climate Change • State Environment Impact Assessment Authority (SEIAA) • Tamil Nadu Pollution Control Board (TNPCB) • Forest Department • Tamil Nadu State Wetland Authority • Tamil Nadu Forest Plantation Corporation Limited (TAFCORN) • Tamil Nadu Biodiversity Conservation and Greening Project (TNBCGP)
3.	**Animal Husbandry, Dairying, Fisheries, and Fishermen Welfare**	• Department of Animal Husbandry and Dairying • Department of Fisheries and Fishermen Welfare • Tamil Nadu Co-operative Milk Producers' Federation Limited
4.	**Housing and Urban Development**	• Tamil Nadu Housing Board • Directorate of Town & Country Planning • Chennai Metropolitan Development Authority (CMDA) • Tamil Nadu Urban Habitat Development Board (TNUHDB) • Housing and Urban Development Corporation (HUDCO) • Chennai Metro Rail Limited
5.	**Municipal Administration and Water Supply**	• Directorate of Municipal Administration • Greater Chennai Corporation (GCC) • Tamil Nadu Water Supply and Drainage Board (TWAD) • Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB) • Tamil Nadu Urban Infrastructure Financial Services Limited (TNUIFSL) • Chennai Rivers Restoration Trust (CRRT) • Tamil Nadu Urban Finance and Infrastructure Development Corporation (TUFIDCO)
6.	**Labour Welfare and Skill Development**	• Department of Employment and Training • Directorate of Industrial Safety and Health • Commissionerate of Labour

GUIDING PRINCIPLES

I. **Design, planning and governance**

- Applying **participatory methods** to develop design strategies that integrate local knowledge and practices.
- Providing strategies to minimise heat exposure
- Assessment of existing policies and regulations that enable heat action planning and make necessary amendments to ensure sustainability and create synergy.

II. **Interventions at scale**

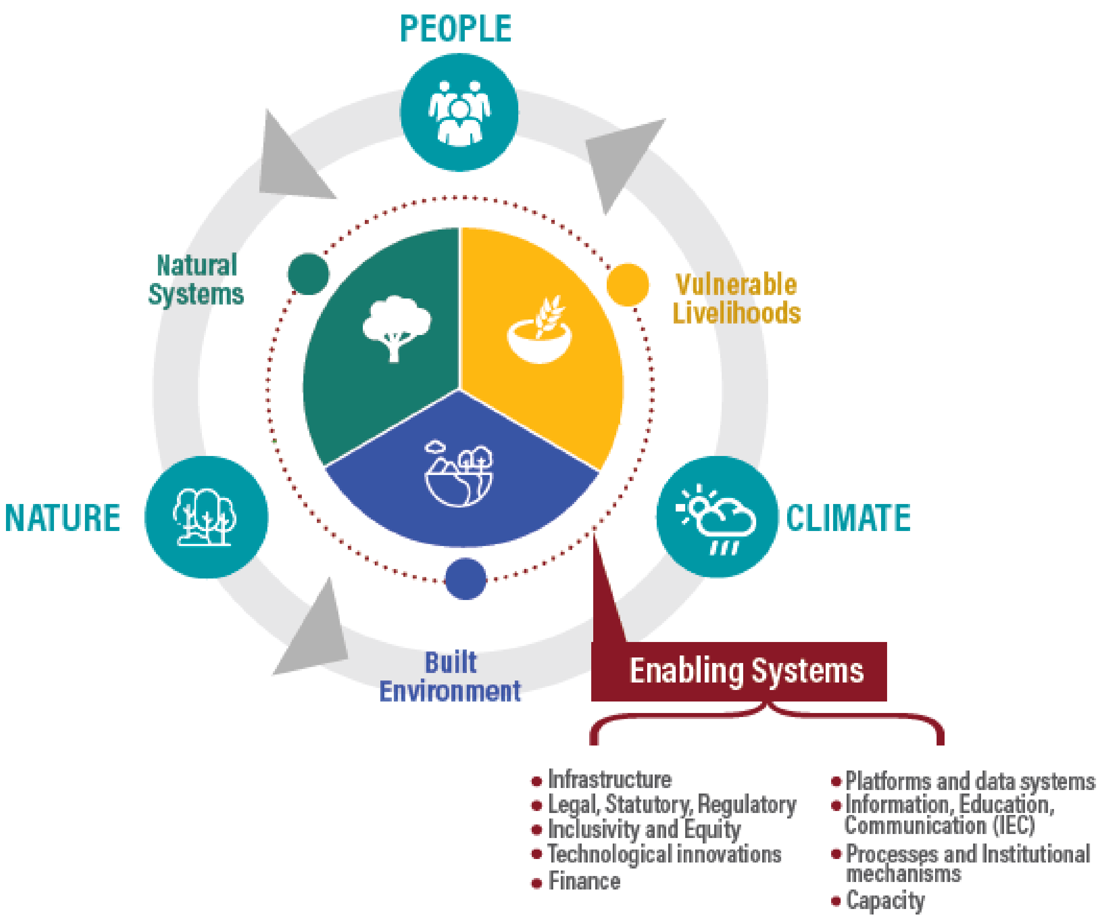
- Investing in evidence-driven decision and collaborative approaches to identify opportunities.
- Leveraging potential across different stakeholder groups ensuring effective communication.

III. **Accelerated access to all**

- Enhancing accessibility to ecological, physical, and social infrastructure to enhance coping capacities (ensuring equity) in communities.

IV. **Enabling inclusion** in the decision-making process to maximise co-benefits in mitigation and adaptation.

These guiding principles build upon the current structure and operationalization of heat plans in India, with scope for future expansion. Tamil Nadu's approach should prioritize transitions within human-centered systems that most influence People, Nature, and Climate—particularly in food, land, water, energy, and urban development. Achieving these transitions also requires shifts in underlying enabling systems, including economic policies, financial frameworks, and governance structures. Such changes should aim to foster economic equality, expand financial resources, and promote inclusive decision-making processes to support sustainable heat resilience.



Source: Authors; based on learnings from Heat Action Network consultations.

Figure 64: System Transition for heat mitigation

Recommendations within the HMS strategy are categorized into short-term and long-term actions, organized across three action pathways outlined below.

I. HEALTH AND WELL BEING

Heat poses significant health risks, especially in regions like Tamil Nadu where 59% of the population is exposed to air temperatures exceeding 35°C. Prolonged exposure to high temperatures can lead to a range of health issues, including heat exhaustion, heatstroke, and the aggravation of pre-existing conditions such as cardiovascular and respiratory illnesses. Vulnerable groups—such as the elderly, children, pregnant women, and outdoor workers—are particularly at risk. High temperatures can also worsen air quality due to poor air circulation, allowing particulate matter and ozone to accumulate to harmful levels. Addressing these health concerns is critical when considering heat and the Urban Heat Island Effect (UHIE) in Tamil Nadu.

Recommendations

Mitigating heat risk and stress in Tamil Nadu requires a comprehensive approach that includes increasing cooling measures, limiting exposure from occupational practices, enhancing healthcare access, and ensuring effective communication about heat mitigation to affected populations.

1. Mitigating Heat Risk and Heat Stress

- Increase cooling measures for both indoor and outdoor locations, particularly in high-risk areas, to reduce the incidence of heat-related illnesses.
- Adapt work schedules and provide access to shaded and air-conditioned rest areas with drinking water and rehydration solutions for outdoor and high-exposure workers to mitigate occupational heat stress.
- Strengthen healthcare access for both preventive and curative care, with a focus on heat-related health services in urban and rural areas experiencing high temperatures.

2. Monitoring and Reducing Human-Wildlife Interactions in Heat

- Enhance monitoring of animal movement and establish communication strategies to reduce human-wildlife conflict, especially in areas experiencing extreme heat.
- Conserve wildlife habitats and ensure essential resources within forest areas to reduce the migration of animals into human settlements, especially during peak heat periods.

3. Baselining and Spatial Mapping for Targeted Interventions

- Use multi-dimensional analysis to map heat-vulnerable clusters, factoring in occupational, demographic, and socioeconomic variables to prioritize support in high-risk areas.
- Identify specific physical and mental health issues linked to heat exposure in different population groups, using thresholds like wet bulb temperature to inform targeted interventions.

- Map outdoor worker populations and livestock populations across vulnerable regions, identifying areas where temperature management and cooling solutions are most needed.
- Correlate high-temperature zones with population densities to identify heat stress risk zones and support distribution planning for resources and cooling interventions.

4. Implementation and Preparedness

- Provide preventive healthcare measures such as cool spaces, drinking water, and rehydration solutions, especially in community hubs such as schools, hospitals, old-age homes, anganwadis, and traffic police stations.
- Train healthcare professionals and paramedics in heat treatment protocols and rapid response for both humans and animals, focusing on vulnerable groups and areas with high heat exposure.
- Partner with private healthcare providers to ensure an adequate supply of healthcare beds during heatwave events, enabling equitable distribution of resources like water and rehydration solutions.
- Allocate essential resources like consistent water and power supply for high-traffic public buildings and animal care centres to maintain comfort during peak heat periods.

5. Planning, Policy, and Governance

- Enhance surveillance and monitoring systems for heat-exacerbated vector-borne and zoonotic diseases, leveraging technology like spatial mapping and AI.
- Ensure off-grid energy solutions for health centres to maintain vaccine storage, operational facilities, and medication availability, particularly in rural or high-heat areas.
- Integrate heat mitigation strategies into existing public health schemes, focusing on support for groups with increased health vulnerability, including pregnant women, children, and older adults.

6. Reducing Heat Exposure

- Schedule outdoor work during cooler parts of the day, provide shaded resting areas, and ensure access to drinking water and rehydration for outdoor workers.
- Maintain thermal comfort in indoor spaces through active and passive cooling techniques integrated into building codes, particularly in community and public buildings.
- Prioritize uninterrupted electricity for cooling solutions in high-traffic and high-risk buildings, such as hospitals, health centres, and schools, especially during peak summer months.

7. Long-Term Ecosystem Resilience and Restoration

- Enhance ecological resilience in urban, rural, and forested zones through the protection of natural spaces, restoring degraded areas, and supporting ecosystem health to withstand extreme heat.
- Initiate greening efforts that enhance biodiversity, reduce soil erosion, and improve thermal comfort by creating shaded areas in critical public spaces, such as transit stops and community centres.
- Implement sustainable water practices like rainwater harvesting, water body conservation, and aquifer management to maintain water resources for communities and ecosystems alike.
- Collaborate with local communities, including forest and fishing groups, to foster long-term stewardship of natural resources, ensuring their health and resilience against extreme temperatures.

II. ENSURING SUSTAINED RESOURCES AND PRODUCTIVITY

The sustainable management of resources is crucial for mitigating the impacts of rising temperatures and heat-related threats across Tamil Nadu, especially in its densely populated urban areas. Addressing urban heat is essential as it affects public health, economic productivity, and resource sustainability. Heat stress challenges sectors such as water supply, energy demand, infrastructure resilience, and the health of vulnerable populations, calling for tailored, sector-specific solutions. The recommendations below outline practical steps for creating resilient urban environments that support sustained resources, productivity, and overall urban resilience against increasing heat risks.

Recommendations

1. Implementation and Preparedness

- Establishing water management systems with drought-resistant infrastructure to support cooling needs during high heat events. Using hydro-meteorological models to forecast water availability under different climate scenarios to inform policymakers for city-level drought prevention. Promoting rainwater harvesting in residential and commercial buildings to reduce dependency on municipal supplies and sustain urban greenery.

- Expanding green cover in urban areas through forestry, green transit corridors, and pocket parks. Strategically placing shade-providing trees and green canopies in heat-prone zones, such as major transit hubs, public parks, and high-density residential areas. Involving community groups in planning and maintaining green spaces to ensure they are sustained as part of heat-resilient urban infrastructure.

- Improving resilience of urban cold chains by investing in heat-resilient infrastructure for the storage and transportation of perishable goods, including cold storage facilities, insulated trucks, and refrigerated storage units. Supporting local food systems, especially under extreme heat, and reducing food spoilage.

2. Planning, Policy, and Governance

- Promoting efficient water use in cities by implementing water-saving practices for urban irrigation and landscaping, such as drip irrigation for public green spaces. Designing zoning regulations to protect urban water bodies and avoid excessive groundwater usage in high-density zones.
- Strengthening building codes and urban planning regulations to include passive cooling and sustainable building materials with high solar reflectance. Mandating cool roofs, green roofs, and other heat-reducing designs in new developments and major renovations. Integrating heat-resilient practices into urban infrastructure projects through partnerships with local governments, planners, and private sector stakeholders.
- Equipping critical urban infrastructure, such as public transportation systems, hospitals, and community centres, with cooling facilities to reduce heat exposure. Creating heat-shelters in strategic locations, offering respite during extreme heat periods. Improving urban transit facilities with shaded walkways, cool resting spots, and access to drinking water.

3. Research, Technology, and Innovation

- Developing smart technology such as IoT sensors and heat stress indices to monitor real-time heat exposure across urban areas. Establishing early warning systems that communicate heat risks to urban residents through mobile applications and public information systems.
- Advancing urban cooling solutions by encouraging R&D in heat mitigation technologies, such as reflective pavements, cool roofing materials, and heat-tolerant plant species for city landscapes. Using predictive modeling to optimize city planning, guiding the development of green spaces, water bodies, and reflective surfaces to reduce heat retention in urban environments.

4. Outreach and Awareness

- Engaging urban communities in heat mitigation efforts through outreach campaigns to raise awareness among residents and businesses about the benefits of green roofs, rainwater harvesting, and other cooling measures. Promoting locally grown, heat-resilient plants and community gardens to support urban greening efforts.
- Facilitating neighbourhood-based cooling initiatives, such as communal gardens, shaded common areas, and water features, which not only reduce temperatures but also foster social engagement. Working with local organizations and NGOs to mobilize urban communities in heat resilience efforts.

5. Sector-Specific Recommendations

Water and Irrigation Management

- Ensuring water supply for cooling during extreme heat through urban rainwater collection, greywater reuse, and protective zoning for natural water bodies.

Green Infrastructure and Urban Forestry

- Expanding green canopy in heat-prone areas by developing tree canopies along high-traffic pedestrian zones, public plazas, and bus shelters to reduce heat stress. Promoting green walls and green rooftops on buildings in high-density neighbourhoods to improve urban cooling and enhance air quality.

Building and Infrastructure Resilience

- Mandating heat-reflective surfaces and green roofs on new and existing buildings to reduce internal temperatures. Providing incentives for developers to adopt energy-efficient and heat-resilient construction practices.

Energy and Cooling Access

- Supporting energy-efficient cooling technologies in low-income urban areas. Integrating renewable energy sources for public cooling facilities to reduce reliance on the power grid during peak heat periods.

III. COOLING SOLUTIONS

This section explores a range of cooling solutions for both urban and rural settings, emphasizing the need to go beyond conventional methods and incorporate innovative, adaptive strategies. The approach integrates passive cooling techniques, traditional practices, and nature-based solutions within the built environment, underscoring the importance of protecting socio-ecological systems. Community engagement is highlighted as essential in developing and sustaining cooling strategies, which serve to alleviate heat-related impacts on human health, productivity, and environmental quality.

To effectively deploy cooling solutions, detailed baselining and spatial mapping of high-heat zones is critical. That's why this study was initiated at the state, district and city level to identify the hotspots. This process identifies zones with high heat prevalence, high-risk public buildings, and areas where vulnerable groups reside, enabling prioritization of interventions. Examples include converting asbestos roofs in low-income housing to cool roofing materials, enhancing the thermal comfort of public gathering spaces, and delineating cool zones that can serve as shelters during heat extremes.

Efforts in Tamil Nadu, led by the Tamil Nadu State Planning Commission (TNSPC) in collaboration with UNEP and CEPT University, aim to address urban heat through the development of Urban Heat Island (UHI) Mitigation Plans. In a state where 48.45% of the population resides in urban areas, the challenges of urban heat are exacerbated by population density, especially in cities like Chennai. Data shows that the Temperature Humidity Index (THI) in Chennai has been on a steady rise, increasing discomfort levels across the year, while regions like Tiruvarur, Thanjavur, Nagapattinam, and Tuticorin experience more days of heat-induced discomfort.

The strategies presented in this chapter address these issues across three categories to enhance thermal comfort at scale in both urban and rural contexts, aiming to create a more resilient environment in response to the growing heat challenges in Tamil Nadu.

Recommendations

Tamil Nadu's climate challenges, particularly in urban areas, necessitate a comprehensive cooling approach. Rising temperatures in cities impact health, productivity, and ecological stability, making it imperative to incorporate sustainable cooling solutions across both built and natural environments. This section outlines actionable recommendations in the areas of implementation, planning, governance, and community engagement to build resilient cities that mitigate heat impacts effectively. Several initiatives, case studies, and policies unique to Tamil Nadu illustrate the importance of targeted interventions that prioritize ecosystem health and community well-being.

1. Implementation and Preparedness

- **Ecological Preservation and Green Spaces**

  Protecting and restoring green areas is essential for both rural and urban heat mitigation. In rural areas, intact ecosystems like forests and wetlands serve as natural buffers against extreme heat and drought, supporting community resilience. Urban environments benefit from green zones such as parks and groves, which lower surface temperatures, provide shaded areas, and improve air quality. A noteworthy example is Guindy National Park in Chennai, which helps modulate urban temperatures while providing ecological, recreational, and health benefits to the city.

- **Tree Planting Initiatives**
  In Tamil Nadu, the Green Tamil Nadu Mission aims to expand tree cover from 23.8% to 33% by 2030-2031. This program involves planting 265 million trees over 13,500 sq. km, prioritizing native and climate-resilient species. This initiative supports urban and rural greening efforts, with trees planted in urban public spaces, institutional lands, and temple premises. Additionally, the Kurunthoppu Thittam project promotes the establishment of native groves at schools and public institutions to enhance urban green cover and mitigate urban heat.

- **Water Resource Protection and Urban Cooling**
  In urban areas, protecting water bodies and infrastructure, such as lakes and wetlands, is critical for alleviating heat. Urban water management practices can create natural cooling effects, with bodies like Cooum River and Pallikaranai Wetland in Chennai acting as heat sinks. Restoring and safeguarding these areas not only mitigates urban heat but also addresses water scarcity and flood risks in the city.

- **Innovative Cooling Infrastructure**
  Tamil Nadu has shown promise in adopting innovative cooling infrastructure. For example, refrigerated storage facilities and cold-chain logistics are being expanded under the Tamil Nadu State Agricultural Produce Marketing Board to improve food resilience during extreme heat. Training programs for farmers and operators on sustainable practices and storage techniques are crucial for building a resilient cold chain, especially during summer months.

2. Planning, Policy, Governance, and Financing

- **Integrating Nature-Based Solutions**
  Cities in Tamil Nadu can enhance climate resilience by integrating Nature-based solutions (NbS) into urban planning. Urban forests, green roofs, and shaded public areas contribute to cooling by providing shade and evapotranspiration. Chennai's Urban Forest Development initiative, for instance, utilizes vacant urban land to establish community forests, offering natural cooling benefits while fostering biodiversity.

- **Alignment with State and International Cooling Initiatives**

  The Tamil Nadu government's partnership with UNEP under the "Cool Coalition" aims to enhance urban design, increase green cover, and plan for extreme heat. This initiative aligns with the India-Denmark Green Strategic Partnership, emphasizing sustainable urban cooling practices. Tamil Nadu's Heat Mitigation Strategy should capitalize on these international collaborations to integrate global best practices into local policies.

- **Promoting Passive Cooling and Energy Efficiency in Buildings**

  Tamil Nadu's focus on passive cooling includes promoting energy-efficient building designs that reflect heat, such as cool roofs and green roofs, which reduce energy demand. The Telangana Cool Roof Policy offers a model for implementing cool roof technology, which Tamil Nadu can adapt to local needs, particularly for schools and hospitals in high-heat urban zones. Additionally, integrating thermally comfortable housing designs with vernacular architecture and locally available sustainable building materials can enhance cooling, making buildings more resilient to high temperatures while also preserving regional architectural styles.

TAMIL NADU'S HEAT MITIGATION STRATEGY ALIGNING WITH EXISTING POLICIES AND SCHEMES

The Tamil Nadu government has allocated a budget of 1.48 crore for the Climate Smart Villages initiative, which aims to introduce climate change mitigation technologies to farmers. This initiative not only raises awareness but also equips farmers with adaptive strategies to address changing weather conditions, with a particular focus on managing heat stress (Business Insider, 2024).

Additionally, the Tamil Nadu Green Climate Company (TNGCC), a Special Purpose Vehicle (SPV) established by the government, is dedicated to addressing the pressing challenges of climate change. TNGCC's mandate includes supporting Tamil Nadu's transition towards a carbon-neutral future through policy guidance, climate adaptation and mitigation initiatives, and promoting environmentally sound technologies.

Leveraging TNGCC's expertise and resources will be essential to implementing the recommendations in the heat mitigation strategy. In partnership with various stakeholders, TNGCC initiated a comprehensive roadmap for urban cooling across Tamil Nadu on February 28, 2024.

- **SOPs for Passive Technology Integration**
  Developing Standard Operating Procedures (SOPs) for passive cooling technologies in public buildings can standardize practices across the state. This includes creating Requests for Proposals (RfPs) for passive cooling technologies and incentivizing developers to adopt energy-efficient designs. SOPs should cover wind tunnels, geothermal cooling, and rooftop insulation techniques to maintain indoor comfort in public spaces.

- **Explore district cooling measures**

  In high-density urban regions to meet aggregated cooling demand: Map and identify opportunities for district cooling measures, especially targeted towards regions with vulnerable populations such as school zones, hospital zones, slum communities, etc.

- **Green public procurement**

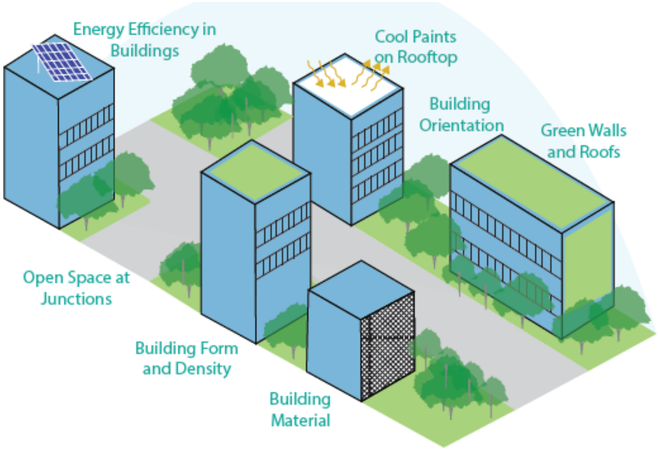
  Promoting green public procurement, establishing suitable guidelines to ensure sustainable practices. For example, Bureau of Energy Efficiency (BEE) star-rated appliances to be mandatorily installed in large buildings to improve energy efficiency. There is good scope in construction tenders, specifically for slum redevelopment and for new residential projects, as a solution to address heat gain issues.

3. Resource Management and Innovation

- **Rainwater Harvesting and Sustainable Energy Use**
  Rainwater harvesting and water conservation are essential in managing drought and heat. Tamil Nadu’s mandate for rainwater harvesting and promotion of solar panels in buildings reduces pressure on water resources and provides renewable energy for cooling needs, especially in remote areas. Wastewater management practices also play a role in water conservation, particularly during summer.

- **Adapting Local Traditional Cooling Practices**
  Traditional materials and designs like lattices and red oxide flooring, common in Tamil Nadu’s vernacular architecture, offer passive cooling benefits that modern construction often overlooks. Encouraging these sustainable design elements in new buildings reduces dependency on mechanical cooling systems and enhances resilience in residential structures.

- **Utilizing Underutilized Spaces for Green Cooling Zones**
  Transforming underutilized spaces into green areas, such as shaded parks, sponge parks or urban gardens, can provide relief in densely populated urban areas. Incentivizing departments to repurpose vacant land for community green zones in Chennai and Coimbatore offers thermal comfort to residents and mitigates urban heat.



Source: Representation of sustainable building design solutions to improve outdoor thermal comfort; adapted from Strategies for Cooling Singapore (Singapore-ETH Centre, 2017).

Figure 65: Depicting a few passive cooling techniques

4. Community Engagement and Capacity Building

- **Community Awareness**
  Educating communities on sustainable practices and responsible cooling solutions is integral to public engagement in heat mitigation. Public awareness campaigns, particularly in urban heat hotspots, can foster community ownership and engagement in cooling solutions.

- **Leveraging CSR for Cooling Solutions**
  Corporate Social Responsibility (CSR) funds provide a viable source for piloting and scaling cooling solutions in urban Tamil Nadu. CSR initiatives can fund research on cooling technologies, provide shade structures in public spaces, or support tree planting in high-density areas. Partnering with corporations to deploy community-centric cooling infrastructure ensures sustainability and maximizes social impact.

ACTION POINTS

Buildings

- Provide resources and incentives for cool roof technologies and energy-efficient designs for building owners.
- Facilitate cooling solutions for residential spaces, including retrofits for improved indoor comfort and lower energy costs.
- Encourage cool roofs and energy-efficient methods in commercial buildings to reduce heat absorption and energy demands.
- *Example Initiative:* The Tamil Nadu Energy Conservation Building Code (TNECBC) 2022 aims to reduce commercial building energy consumption, with TNECBC-compliant buildings projected to use 50% less energy than conventional structures.
- **Nodal Departments:** Department of Housing and Urban Development, Tamil Nadu Energy Development Agency (TEDA), Tamil Nadu Pollution Control Board (TNPCB), Department of Municipal Administration and Water Supply (MAWS), Department of Revenue and Disaster Management, Tamil Nadu Generation and Distribution Corporation, Department of School Education, Department of Environment and Forests, Department of Health and Family Welfare.

Green Spaces & Parks

- Enhance existing parks and establish new green spaces with trees and vegetation for cooling and community gathering.
- Convert hardscaped areas into pocket parks and prioritise green strategies in areas with limited vegetation.
- *Policy Framework:* The Tamil Nadu Combined Development and Building Rules include provisions to increase green spaces, buffer zones around water bodies, and dedicated open space reservations.
- **Nodal Departments:** Department of Municipal Administration and Water Supply (MAWS), Department of Housing and Urban Development, Department of Environment and Forests, Department of Revenue and Disaster Management, Department of Highways and Minor Ports, Department of Rural Development and Panchayat Raj.

Streets

- Implement shaded, vegetated, and cool pathways for local destinations and main streets.
- Prioritise converting street areas into green spaces and small parks, offering shade and cooling for pedestrians.
- *Example Initiative:* Under the 'Smart Complete Street Project,' Tamil Nadu plans to develop 1,656 km of streets into vibrant public spaces. These 'Complete Streets' aim to provide inclusive, safe environments for all users, supporting various age groups, genders, and physical dispositions.
- **Nodal Departments:** Directorate of Town and Country Planning, Chennai Metropolitan Development Authority (CMDA), Tamil Nadu Urban Habitat Development Board, Greater Chennai Corporation (GCC), Department of Environment, Forests, and Climate Change.

Design

Incorporate heat resilience into zoning ordinances, development reviews, and design guidelines to mitigate urban heat island effects in new projects.

Prioritise affordable housing with cool design features, ensuring equitable access to comfortable living conditions.

- **Nodal Departments:** Department of Housing and Urban DevelopmentTamil Nadu Urban Habitat Development Board (TNUHDB), Department of Municipal Administration and Water Supply (MAWS), Department of Rural Development and Panchayat Raj, Tamil Nadu Town and Country Planning Department, Tamil Nadu Real Estate Regulatory Authority (TNRERA).

4.2 CITY LEVEL RECOMMENDATIONS

City-level strategies in Tamil Nadu aim to modify urban landscapes to reduce heat accumulation and enhance thermal comfort across the state's rapidly growing cities. Key areas of intervention include expanding green cover, improving surface materials, restoring natural heat sinks, and promoting sustainable transportation systems. These initiatives align with Tamil Nadu's broader climate action goals and support the unique environmental and socio-economic needs of the state.

4.2.1 INCREASE OF GREEN COVER

Expanding green cover across urban areas in Tamil Nadu can significantly mitigate UHIE by providing shaded areas, cooling effects through evapotranspiration, and improving air quality. Given Tamil Nadu's tropical climate, increasing urban greenery is critical to reducing ambient temperatures, especially during peak summer months. Integrating green spaces into urban planning frameworks, such as City Master plans, Development Green Zones, and Greening in OSR lands, riverbanks etc, establishes a structured pathway for enhancing greenery in urban environments across the state.

In Tamil Nadu, green cover initiatives can focus on urban forestry, green transit corridors, and pocket parks within residential and commercial zones. Urban forestry, particularly in larger cities, provides extensive shading, while green transit corridors with tree-lined walkways and bike lanes help reduce heat exposure along busy routes. Smaller green spaces, such as pocket parks and residential gardens, play a significant role in cooling densely populated neighbourhoods.

To maximize the cooling effect of green cover, native plant species should be prioritized, as they are well-suited to Tamil Nadu's climate, with high tolerance to heat and varying rainfall patterns. These species provide shade and cooling benefits with minimal maintenance, making them ideal for urban settings. Regular management and appropriate placement will ensure optimal cooling from urban green cover and aid in stormwater management.

Projected Outcomes:

- **Temperature Reduction**: Native green cover can lower ambient air temperatures through shading and evapotranspiration.
- **Environmental Benefits**: Increased greenery contributes to stormwater management, improves air quality, and enhances carbon sequestration, supporting public health and resilience against climate change in Tamil Nadu.

4.2.2 CHANGE OF SURFACE COVER

Replacing traditional paved surfaces that absorb heat with materials designed to reflect or retain less heat can effectively reduce surface and ambient temperatures across Tamil Nadu's cities. This approach is especially relevant in densely built areas, where conventional paving contributes significantly to the UHIE.

Key focus areas for Tamil Nadu's surface cover initiatives include using permeable (water-retentive) surfaces with high void percentages, which help absorb rainwater, and adopting cool pavements with high Solar Reflectance Index (SRI) to reduce solar heat gain. These materials not only reduce surface temperatures but also help in managing stormwater, which is essential for flood-prone urban areas like Chennai during the monsoon season.

Cool pavements include a range of materials and technologies designed to retain less heat and maintain lower surface temperatures compared to conventional pavements. In Tamil Nadu, these pavements can play a significant role in addressing urban heat islands, which arise partly due to the increased heat absorbed by paved surfaces in densely populated areas.

In Tamil Nadu, the Smart Cities scheme provides an excellent opportunity to explore and implement cool pavements as a practical solution for urban cooling. By integrating cool pavement technologies in smart city plans, Tamil Nadu can address urban heat island effects more effectively, reducing surface temperatures in densely populated areas. This initiative can also enhance the resilience of urban infrastructure to heat while contributing to improved water quality and overall urban comfort, aligning with the broader goals of the Smart Cities mission.

Conventional pavements, typically made of asphalt and concrete, can reach peak surface temperatures of 48–67°C during summer. This heat is absorbed and transferred to subsurface layers, releasing warmth back into the atmosphere at night, which exacerbates night-time urban heat. Additionally, these heated surfaces can warm stormwater runoff, which flows into local water bodies, impacting water quality and local ecosystems. Adopting cool pavements can thus help mitigate these heat and water quality challenges, supporting Tamil Nadu's efforts to improve urban climate resilience.

Projected Outcome:

- **Cooler Surfaces**: By minimizing solar heat absorption and re-radiation, permeable and cool pavements contribute to a cooler urban environment and mitigate UHIE, particularly at night.
- **Improved Water Management**: Permeable surfaces help manage stormwater more effectively, reducing urban flooding risks during intense rainfall.

4.2.3 RESTORATION OF NATURAL HEAT SINKS

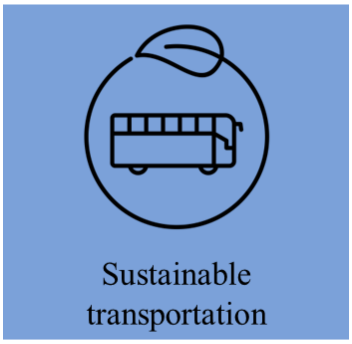
Restoring natural heat sinks, such as water bodies and large green open spaces, provides essential cooling benefits in Tamil Nadu's urban centres. Land-use guidelines in TP schemes and ecosystem management policies can support the preservation and expansion of these natural cooling elements.

In Tamil Nadu, this initiative involves restoring and maintaining water-sensitive areas like lakes, wetlands, rivers, and ponds. For instance, Chennai's water bodies, which historically served as natural coolers, have seen degradation but could be restored to reclaim their cooling potential. Similarly, creating green open spaces in cities like Madurai and Coimbatore, where urban expansion has encroached upon traditional green areas, will offer respite from urban heat. Water-sensitive urban design principles, which use natural and artificial water features to cool surrounding areas, should be a priority in these cities.

Projected Outcome:

- **Enhanced Cooling**: Restoring natural heat sinks helps lower temperatures by utilizing the natural cooling effect of water and green spaces, which absorb heat and promote evapotranspiration.
- **Ecosystem Benefits**: Preserved green spaces and water bodies contribute to biodiversity, support groundwater recharge, and create a balanced urban ecosystem.

4.2.4 SUSTAINABLE TRANSPORTATION

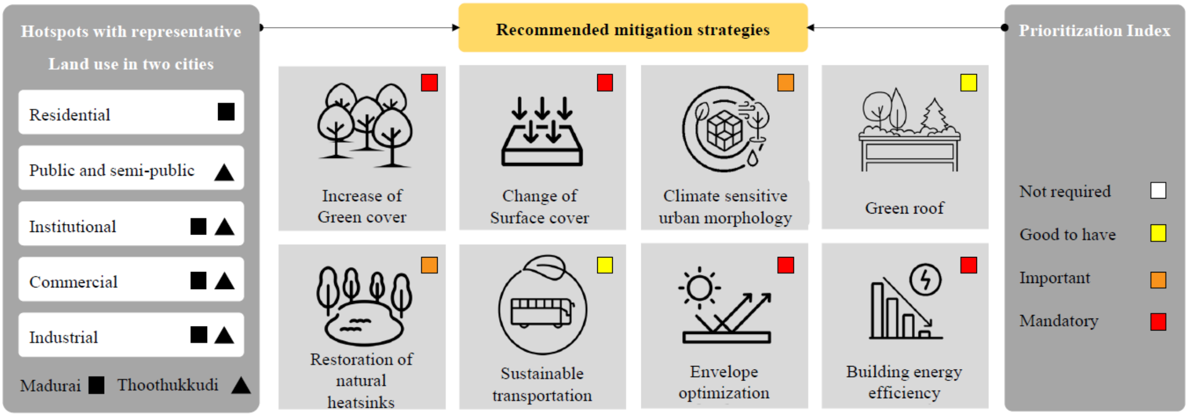


Promoting sustainable transportation reduces heat emissions from vehicles and enhances air quality across Tamil Nadu. Effective transport policies, incentivizing cleaner technologies, and better traffic management are essential to lowering UHIE-related emissions, particularly in highly populated cities like Chennai, where vehicular traffic is a significant contributor to urban heat.

In Tamil Nadu, sustainable transportation initiatives include incentivizing the use of low-emission and battery-operated vehicles, developing infrastructure for non-motorized transport (NMT) like shaded bicycle lanes, and enhancing public transportation options. By making sustainable transportation more accessible and attractive, Tamil Nadu can encourage a shift from private vehicles to cleaner, more energy-efficient transport modes.

Projected Outcome:

- **Reduced Emissions**: A reduction in vehicular heat emissions will lower UHIE, especially in congested areas.
- **Improved Air Quality**: Reduced reliance on fossil-fuel-based transportation will lead to cleaner air, benefiting both public health and the environment.



Based on the recommendations suggested above on the mitigation measures at city level, the above figure pictures the mitigation measures with priority index for Madurai and Thoothukudi districts which are discussed in detail in Chapter 3. The profile of every city varies, so it becomes essential to carry out urban heat island assessment before identifying the mitigation measures to be implemented.

4.3 BUILDING LEVEL RECOMMENDATIONS

At the building level, UHIE mitigation can be achieved through climate-sensitive urban design, green roofs, optimized building envelopes, and energy efficiency. These strategies directly reduce heat within and around buildings, minimizing the need for artificial cooling and contributing to urban comfort.

4.3.1 CLIMATE SENSITIVE URBAN MORPHOLOGY

Building structures and urban layouts that consider climate factors can reduce heat accumulation and improve natural ventilation. Integrating these climate-sensitive principles into TP schemes, Development Control Rules, Form-Based Codes, and building bylaws will improve thermal comfort in urban centres across Tamil Nadu.

Urban morphology recommendations include appropriate building orientation, regulated Floor Space Index (FSI) and setbacks to promote airflow, and enhancing sky view factors, particularly in dense neighbourhoods. Buildings positioned near open spaces with setbacks allow for effective urban cooling, minimizing heat buildup.

Projected Outcome:

- **Lower Cooling Demand**: Passive cooling techniques through shading and ventilation reduce energy requirements for cooling in dense urban environments.
- **Improved Night-time Comfort**: Enhanced sky view factors allow trapped heat to dissipate, lowering UHIE effects, especially during hot summer nights.

4.3.2 GREEN ROOF

Green roofs are an emerging technology that can help communities mitigate urban heat islands. A green roof is a vegetative layer grown on a rooftop. As with trees and vegetation elsewhere, vegetation on a green roof shades surfaces and removes heat from the air through evapotranspiration. These two mechanisms reduce temperatures of the roof surface and the surrounding air. The surface of a vegetated rooftop can be cooler than the ambient air, whereas conventional rooftop surfaces can exceed ambient air temperatures by up to 90°F (50°C).2 Green roofs can be installed on a wide range of buildings, including industrial, educational, and government facilities; offices; other commercial property; and residences.

Integrating green roofs into buildings provides insulation, reduces solar heat gain, and offers valuable ecosystem services. Encouraging green roofs through incentives and subsidies in Tamil Nadu can reduce UHIE effectively, particularly in high-density urban areas.

Green roofs, whether extensive (low-maintenance) or intensive (with rooftop gardens or farming), help in lowering rooftop temperatures. In Tamil Nadu's cities, green roofs will not only minimize solar heat gain but also help manage rainwater runoff, a critical factor in flood-prone areas.

Projected Outcome:

- **Reduced Indoor Temperatures**: Green roofs lower cooling demand within buildings.
- **Stormwater Management**: They help absorb rainwater, reducing urban runoff and mitigating flood risks during heavy rains.

On a typical day, the Chicago City Hall green roof measures almost 80°F (40°C) cooler than the neighboring conventional roof.

Figure 66: Temperature Differences between a Green and Conventional Roof

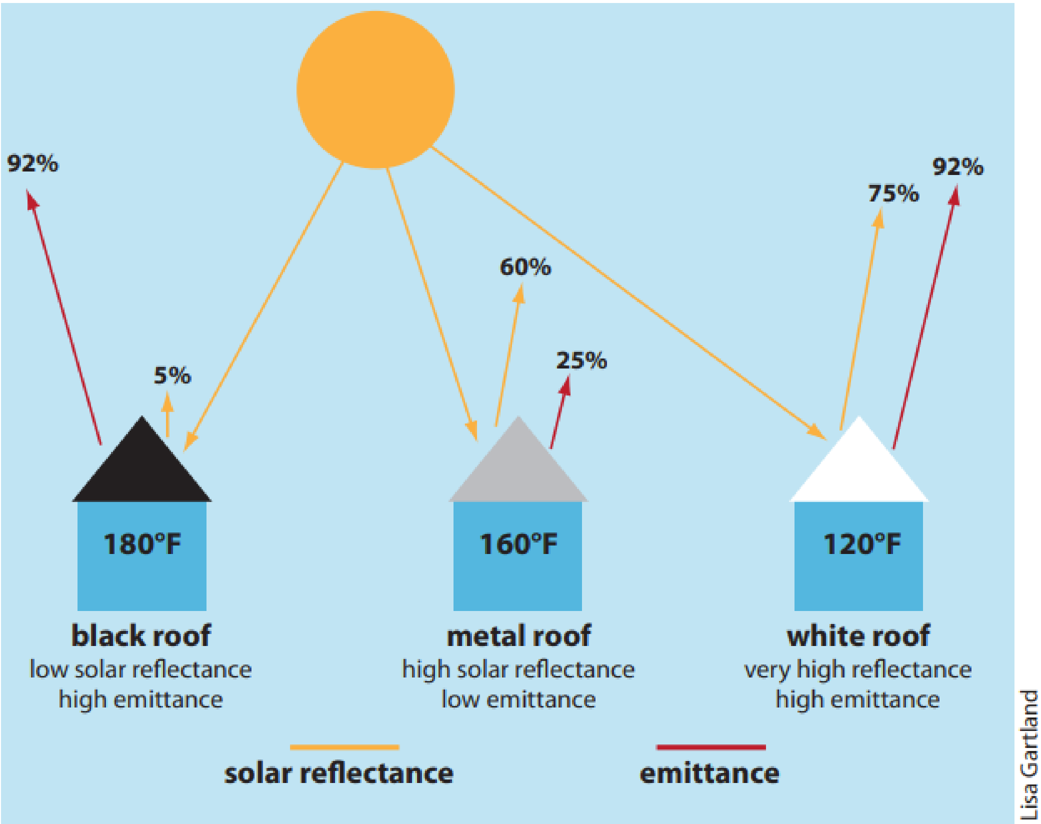
4.3.3 COOL ROOF

"Cool roofing" refers to the use of highly reflective and emissive materials. "Green roofs" refer to rooftop gardens.

Cool roofing can help address the problem of heat islands, which results in part from the combined heat of numerous individual hot roofs in a city or suburb. Cool roofing products are made of highly reflective and emissive materials that can remain approximately 50 to 60°F (28-33°C) cooler than traditional materials during peak summer weather. Building owners and roofing contractors have used these types of cool roofing products for more than 20 years. Traditional roofs in the United States, in contrast, can reach summer peak temperatures of 150 to 185°F (66-85°C),2 thus creating a series of hot surfaces as well as warmer air temperatures nearby. The use of cool roofs as a mitigation strategy brings many benefits, including lower energy use, reduced air pollution and greenhouse gas emissions, and improved human health and comfort. At the same time, there can be a cost premium for some cool roof applications versus traditional roofing materials.

Projected Outcome:

- Decreased cooling electricity consumption due to reduced need for air conditioning, especially valuable during Tamil Nadu's hot seasons.
- Reduced peak electric demand which can alleviate pressure on the grid during peak heat periods, helping prevent power outages.
- Cost savings on cooling equipment downsizing as cooler roofs reduce indoor temperatures, enabling smaller, more efficient AC systems.



On a hot, sunny, summer day, a black roof that reflects 5 percent of the sun's energy and emits more than 90 percent of the heat it absorbs can reach 180°F (82°C). A metal roof will reflect the majority of the sun's energy while releasing about a fourth of the heat that it absorbs and can warm to 160°F (71°C). A cool roof will reflect and emit the majority of the sun's energy and reach a peak temperature of 120°F (49°C).

Figure 67 : Example of Combined Effects of Solar Reflectance and Thermal Emittance on Roof Surface Temperature

4.3.4 ENVELOPE OPTIMIZATION

Optimizing building envelopes by using reflective materials, shading devices, and insulation reduces heat transfer and improves indoor comfort. Tamil Nadu's building bylaws, energy conservation codes, and compliance standards can guide these improvements. Using cool roof technology, optimizing window-to-wall ratios, and installing thermal insulation for walls and roofs are effective ways to reduce indoor temperatures. This optimization is especially important for dense urban areas in Tamil Nadu, where reducing heat transfer will improve comfort and reduce energy consumption.

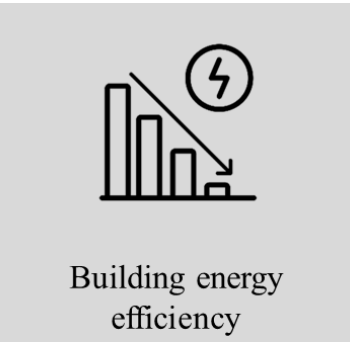
Projected Outcome:

- **Energy Efficiency**: Lower heat transfer reduces the need for air conditioning, conserving energy.
- **Improved Indoor Comfort**: Cool roofs, shaded windows, and proper insulation create more comfortable indoor environments in Tamil Nadu's hot climate.

4.3.5 BUILDING ENERGY EFFICIENCY

Enhancing energy efficiency through HVAC systems, district cooling, and energy conservation standards will reduce anthropogenic heat emissions. Institutionalizing energy conservation codes across Tamil Nadu will provide a standardized approach to achieving building energy efficiency.

Key measures include using energy-efficient HVAC systems, optimizing air conditioning, and implementing district cooling in high-density areas. These improvements will reduce the overall cooling load and lower electricity costs, especially important in Tamil Nadu's densely populated urban areas where anthropogenic heat contributes significantly to UHIE.



Projected Outcome:

- **Lower Cooling Load**: Energy-efficient systems reduce energy consumption and heat emissions.
- **Reduced Urban Heat**: Optimized cooling systems minimize UHIE, particularly in densely built-up areas.

4.4 WAY FORWARD

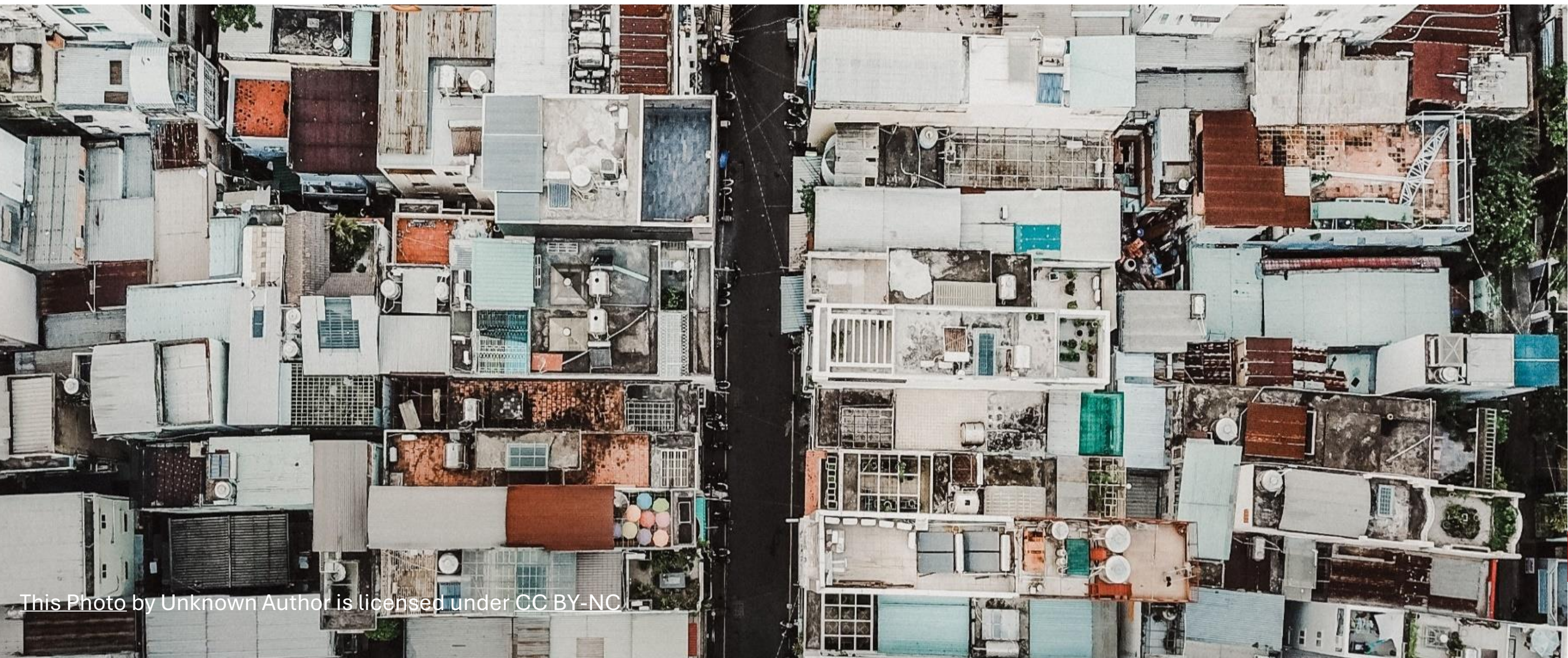
The recommendations outlined in this report present a comprehensive strategy for mitigating Urban Heat Island Effect (UHIE) across state, city, and building levels in Tamil Nadu. By leveraging a combination of strategic microclimate assessments and targeted interventions, Tamil Nadu can effectively reduce the impacts of UHIE, enhance urban comfort, and lower energy demands state-wide.

At the state level, the approach centres on policy frameworks, large-scale green infrastructure, and sustainable urban planning standards that prioritize climate resilience. Collaborative efforts among state government departments, environmental agencies, and urban planning authorities are essential to implement policies that integrate green spaces, water bodies, and sustainable transportation systems into the urban landscape. State-level policies should be developed to encourage local governments to adopt climate-sensitive guidelines for urban development, while also providing the financial and technical support necessary for effective implementation.

City-level actions should focus on integrating UHIE mitigation measures into urban master plans, prioritizing the creation and preservation of green spaces, the use of cool pavements, and the promotion of non-motorized and sustainable transportation options. As cities like Chennai, Coimbatore, and Madurai expand, it is crucial to incorporate cooling solutions into infrastructure projects, ensuring that public spaces, transportation corridors, and residential neighbourhoods are designed to minimize heat retention. Partnerships with local NGOs, resident associations, and businesses will enhance community involvement and enable the development of solutions tailored to each city's unique needs.

Mitigating heat at the building level involves adopting climate-sensitive design principles, such as cool roofing, green walls, and energy-efficient materials, to reduce indoor temperatures and energy demand. By updating building codes to include UHIE mitigation requirements, such as the use of reflective surfaces, shading structures, and natural ventilation, Tamil Nadu can ensure that both new and existing buildings contribute to the state's cooling goals. Encouraging buildings to retrofit with these features and creating model demonstration projects will encourage widespread adoption.

Moving forward, implementing these recommendations will require sustained collaboration among urban planners, government bodies, private sector partners, and community stakeholders. Establishing a dedicated task force or working group to oversee and coordinate efforts across levels can streamline implementation, monitor progress, and ensure accountability. Detailed microclimate assessments and ongoing monitoring will provide data-driven insights into the effectiveness of interventions and guide future decisions. Engaging citizens in the process, through awareness programs and public consultations, will strengthen community resilience and foster a shared commitment to climate adaptation.



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