EVALUATING HEAT RISK IN URBAN AREAS:-
A CASE STUDY OF INDORE CITY

MASTER OF PLANNING

(Urban Planning)

by

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by

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Under The Supervision of

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ABSTRACT

Rapid urbanisation and climate change have intensified heat stress across Indian cities, making neighbourhood-level analysis critical for understanding local variations in exposure and vulnerability. Rapid urbanisation and changing climate conditions are intensifying overall heat stress in Indian cities, making it essential to analyse neighbourhoods at a finer scale to understand variations in exposure and vulnerability. study investigates heat resilience across different urban neighbourhood forms (UNF) and explores how their physical characteristics influence microclimate and thermal comfort. research is structured in two phases. involves a review of national, state, and city-level policies such as the National Action Plan on Climate Change (NAPCC), India Cooling Action Plan (ICAP), Heat Action Plans, AMRUT 2.0, Smart Cities Mission, and the Energy Conservation Building Code. aim is to evaluate current approaches to heat mitigation and highlight the absence of neighbourhood-specific guidance. This phase also examines key urban form parameters including built density, land-use diversity, street layout, building patterns, and open-space structure to classify neighbourhood typologies and understand their spatial characteristics. applies GIS and remote sensing methods to develop a neighbourhood-level spatial database integrating land surface temperature (LST), vegetation indices, built-up attributes, and socioeconomic indicators. datasets are used to construct a heat-risk model comprising hazard, exposure, and vulnerability components. The analysis produces heat-risk maps that pinpoint hotspots and demonstrate how much variations in density, street geometry, shading, and greenery affect thermal conditions. Thermal simulations further validate the relationship between urban morphology and surface temperatures.

Keywords: Urban Heat Island (UHI), Urban Heat Risk, Land Surface Temperature (LST)
Local Climate Zone (LCZ), Urban Form, Surface Urban Heat Island (SUHI)

सारांश

भारत में तीव्र शहरीकरण और जलवायु परिवर्तन ने शहरी क्षेत्रों में गर्मी के प्रभाव को अत्यधिक बढ़ा दिया है, जिससे पड़ोस-स्तर पर तापीय जोखिम का विश्लेषण आवश्यक हो गया है। यह अध्ययन शहरी मोहल्लों की गर्मी-सहनशीलता का आकलन करता है और यह समझने का प्रयास करता है कि विभिन्न शहरी रूप-रचनाएँ स्थानीय सूक्ष्म जलवायु और तापीय आराम को किस प्रकार प्रभावित करती हैं। शोध दो चरणों में किया गया है। प्रथम चरण में राष्ट्रीय जलवायु परिवर्तन कार्य योजना, भारत शीतलन कार्य योजना, हीट एक्शन प्लान, अमृत 2.0, स्मार्ट शहर मिशन तथा ऊर्जा संरक्षण भवन संहिता जैसी राष्ट्रीय, राज्य और नगर-स्तरीय नीतियों का अध्ययन किया गया, ताकि तापीय जोखिम में कमी से संबंधित वर्तमान दिशा-निर्देशों तथा मोहल्ला-स्तरीय योजनाओं में मौजूद अंतरालों को स्पष्ट रूप से समझा जा सके। इसी चरण में निर्माण घनत्व, भूमि-उपयोग मिश्रण, सड़क जाल, भवन विन्यास और खुले स्थानों की संरचना जैसे प्रमुख रूपात्मक मानकों के आधार पर विभिन्न प्रकार के पड़ोसों का वर्गीकरण किया गया। द्वितीय चरण में भू-स्थानिक सूचना प्रणाली और उपग्रह आधारित आंकड़ों की सहायता से भू-सतह तापमान, हरित क्षेत्र सूचकांक, निर्मित क्षेत्र और जनसांख्यिकीय आँकड़ों को एकीकृत करते हुए एक विस्तृत स्थानिक डेटाबेस तैयार किया गया, जिसे जोखिम, संवेदनशीलता और अनावरण पर आधारित गर्मी जोखिम मॉडल में सम्मिलित करके मोहल्ला-स्तर की तापीय संवेदनशीलता का मानचित्रण किया गया। तापीय अनुकरण ने गर्मी-प्रभावित क्षेत्रों की पहचान को स्पष्ट किया और यह दर्शाया कि घनत्व, सड़क संरचना और हरियाली में अंतर स्थानीय तापमान को किस प्रकार प्रभावित करते हैं। अध्ययन के आधार पर छाया में वृद्धि, हरित आवरण का विस्तार, परावर्तक सामग्री का उपयोग, सड़क ढाँचे में सुधार तथा वायु संचरण गलियारों के विकास जैसी स्थान-विशिष्ट रणनीतियाँ सुझाई गई हैं, ताकि शहरों में जलवायु-संवेदी और गर्मी-सहिष्णु मोहल्लों की योजना को अधिक प्रभावी बनाया जा सके।

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LIST OF ABBREVIATION

Abbreviation	Full Form
LST	Land Surface Temperature
WUDAPT	World Urban Database and Access Portal Tools
LCZ	Local Climate Zone
UHI	Urban Heat Island
BSF	Building Surface Fraction
PSF	Pervious Surface Fraction
ISF	Impervious Surface Fraction
SVF	Sky View Factor
NDBI	Normalized Difference Built-up Index
NDVI	Normalized Difference Vegetation Index
GIS	Geographic Information System
RS	Remote Sensing
LULC	Land Use Land Cover
DEM	Digital Elevation Model
GEE	Google Earth Engine
ESA	European Space Agency
NASA	National Aeronautics and Space Administration
OSM	OpenStreetMap
UFT	Urban Form Typology

Chapter - 1
Introduction

1.1 Introduction

Heat risk is characterized as the potential harm that an individual, infrastructure, and the environment may face during heat extreme conditions. Its formation is controlled by three determining factors, namely: the degree of exposure to high temperature, sensitivity of population and systems to heat, and its ability to adapt or respond appropriately. (Uddin et al. 2020).

Heat risk in cities arises from the combined effect of hazard, exposure, and vulnerability. The diagram illustrates how these three elements interact to influence overall urban heat risk. Hazard refers to environmental conditions that generate heat stress, such as high temperatures, pollution, and waste heat emissions. The risk of heat in cities is created by three factors: hazard, exposure, and vulnerability. The diagram below illustrates the interrelationship of these three components on overall urban heat risk. Hazard can be described as environmental conditions that create heat stress, such as high temperatures, pollution, and waste heat emissions. Exposure reflects the degree to which people and the built environment come into contact with hazardous conditions. Vulnerability indicates how sensitive communities are to heat and how well they can cope, including access to healthcare, adaptive capacity, and social conditions. Together, these components determine urban resilience in shaping how well a city can resist, absorb, and recover from heat-related impacts.

Urban resilience develops through three connected processes resistance, response, and adaptation. Resistance addresses on reducing heat-related hazards, deals with managing the immediate impacts, and adaptation involves long-term measures improving landscape morphology to lower exposure, elements show demonstrate cities can reduce overall heat risk and protect their safeguard residents from extreme heat. (Dinh et al., 2025)

It develops through three connected processes: resistance, response, and adaptation. Resistance focuses on heat-related hazards reduction, deals with the immediate impact's management, while adaptation involves long-term measures in improving the

landscape morphology to lower the exposure. Elements that show cities can take to reduce overall heat risk and safeguard their residents from extreme heat include.

In India, urban areas are facing growing risks from climate-related hazards such as heatwaves, intense rainfall, these events increasingly disrupt infrastructure, housing, and daily life especially in fast-growing cities with complex and rapidly changing settlement patterns of the city resilience of urban environments shaped not only on governance and infrastructure but also their physical layout and built environment, collectively defined as urban form typologies (UFTs). (Li & Gou, 2025)

Understanding how different urban form typologies influence vulnerability and adaptive capacity under climate stresses is essential for developing effective long-term planning and design strategies study highlights on integrating spatial analysis and urban morphology tools to evaluate heat resilience and their targeted strategies for enhancing the sustainability of vulnerable urban settlements. This aims to contribute to climate-adaptive urban planning tailored to the diversity of Indian cities' urban forms. (Hu, 2025)

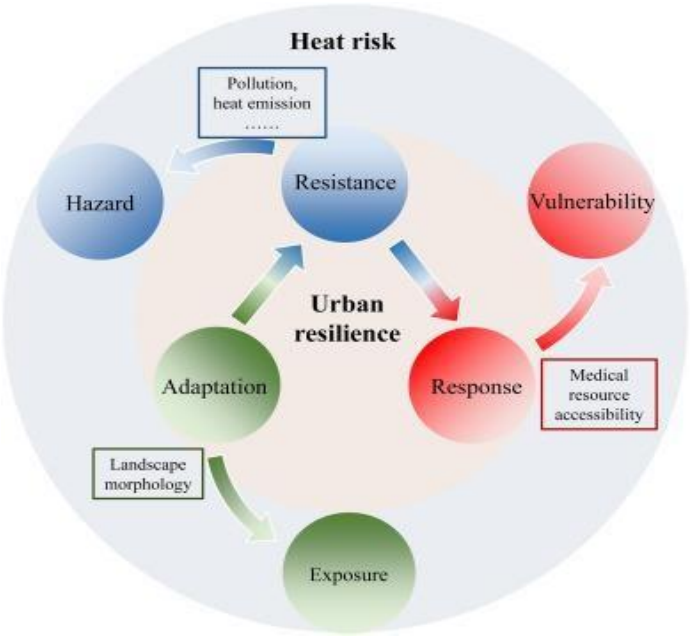


Figure: 1 Urban resilience approach *Source: Modified from Merrow, S., Newell, J. P., & Stults, M.*

Heat resilience in urban neighborhoods depends on how hazard, exposure, and vulnerability combine to influence heat-related impacts. This framework explains that urban resilience is highlights through three interconnected processes. *Resistance*

reflects the neighborhood's ability to withstand heat stress, shaped by aspects such as ambient pollution and heat emissions. Response describes how well communities can act during heat events, which is influenced by the availability and accessibility of critical services, including healthcare. Adaptation is guided by elements of urban form and landscape features that help neighborhoods adjust to increasing temperatures and moderate heat buildup. Together, process offer a complete view of how different urban environments experience, cope with, and recover from heat risks. (Abedrabboh et al., 2025)

Urban Resilience refers to how well a city and its interdependent systems maintain Operations in times of extreme stress or negative pressure or shock and are still able to accommodate development long-term. Increasing temperatures result in negative impacts on infrastructures (living conditions), health, and everyday life, creating an increased demand for adopting resilient strategies in urban settings compared to their rural counterparts. The causes of this increase in temperature include Human activities, which change the way land is used, decrease vegetation through deforestation and the burning of fossil fuels, and produce waste heat. For cities and urban citizens, urban heat creates vulnerability to the effects of urban heat and other factors. To increase urban resilience altogether, several adaptation strategies have been introduced that will allow cities to develop proactively, lessen the impact of urban heat, and continue to function sustainably. As cities are rapidly urbanizing and the effects of climate change continue to alter local climate conditions, (for example) by changing the types of vegetation and increasing extreme weather patterns, the need for increased capacity for urban centers to adapt will continue to grow. (Jin et al., 2025)

Resistance refers to the ability of the neighborhood to resist heat stress, influenced by ambient pollution and heat emissions, among other factors. Response alludes to how well people can act during the heat event, influenced by the availability and accessibility of services such as healthcare. Adaptation will depend upon elements of urban form and landscape features enabling neighborhoods to adjust to the rising temperature and moderate heat buildup. Processes collectively provide a holistic understanding of how different urban environments experience, cope with, and recover from heat risks.

1.2 Background of the study

Neighborhoods are the fundamental geographic unit of a city; how people experience and manage climate-induced stress and challenges occurs at the neighborhood scale. Rapid urbanization in India has resulted in several distinct characteristics that have defined India's environmental response system (i.e., urban density) versus its urban/rural interaction (i.e., informal settlements, planned neighborhoods these two types of neighborhood have very different rates and types of exposure to climate-related events like heat waves, flooding, and torrential rains. Therefore, the experience of climate-induced vulnerability is unique to each individual neighborhood and needs to be assessed as such instead of relying on city-level assessments, which often overlook neighborhoods. (Li and Gou 2025).

The structure, density, and spatial configuration of neighborhoods are the decisive factors that shape the way heat is accumulated and released in cities. Densely built areas with minimal vegetation are more likely to intensify heat accumulation and limit natural airflow, whereas more open and greener neighborhoods can act to moderate microclimatic conditions (Hu 2025). Consequently, understanding heat resilience at the local neighborhood level demands a highly detailed understanding of how built form, open space, and socio-economic characteristics interact. This study uses spatial and morphological analysis to explore how different neighborhood typologies exacerbate or reduce heat vulnerability, and thus provide insights into their relative capacity to support thermal comfort and climate resilience.

Inn Indian cities, where settlements range from dense inner-city clusters to dispersed peri-urban expansions, these morphological contrasts create a unequal patterns of risk and adaptation framework that evaluates neighbourhood-level heat resilience using GIS-based mapping, urban morphology indicators, and vulnerability assessment or sensivity analysis refer to *Figure 1***.**

Main findings inform planning methods and design guidelines that strengthen local level resilience while aligning with comprehensive adaptive climate city. (Abedrabbohetal.2025).

Rapid urbanization around the world presents urban centres with an array of challenges and opportunities. Urban sprawl (a term that typically refers to the unplanned or deceptive nature of horizontal growth in cities), increases the cost of providing urban infrastructure, raises the level of environmental degradation caused by urbanization, and waste land, as the vast majority of Indian cities are continuing to grow outwards rather than upwards similarly to how the high growth rates of built surfaces have occurred at 1.5 times faster than the total population growth rate worldwide. (Angel et al., 2012), the impacts are extending beyond governance and service provision they significantly amplify climate-related vulnerabilities, particularly urban heat stress.

Evaluate the heat resilience of cities, we must understand how urban form, open space systems, and socio-economic conditions interact with each other at the neighborhood scale. This study will explore the relationship between urban form and heat vulnerability by adopting a spatial and morphological perspective, and by evaluating how cities create neighborhood typologies that can either exacerbate or reduce heat vulnerability. Based on the findings of this research, we hope to provide useful information on how to develop climate-responsive urban design and neighborhood-level adaptation strategies. Urban morphology in India is a primary driver of heat risk and resilience, as urban forms are directly connected to microclimates, exposure levels, and the adaptive potential of communities and neighborhoods. Unprecedented levels of rapid urbanization have created new forms of urban landscape that have often intensified the urban heat island (UHI) phenomenon. Urban areas that are densely developed with materials that retain heat, such as concrete and asphalt, can absorb and hold onto solar radiation, leading to urban temperatures that are significantly higher than rural temperatures. As a result, elevated temperatures cause increased heat stress on populations, especially within informal settlements and high-density neighborhoods that are lacking shade, green cover, and sufficient ventilation to mitigate heat effects. Research consistently demonstrates that several characteristics of urban form, such as street orientation, building density, block arrangement and organization, open space, and the placement of vegetated spaces within the urban environment shape how heat and air flows in and out of a neighborhood, and thus determine how neighborhoods feel thermally comfortable and how they experience heat. Research regularly shows that an element of urban form such as street orientation, building density, block arrangements, and the distribution of open and vegetated spaces shape airflow patterns and heat

accumulation these factors determine neighborhood-scale thermal comfort and shape the extent of risk from extreme heat events. (D. Wang et al., 2025)

The adaptation pathways framework recommends sequencing interventions from incremental adjustments to transformative changes that engage with both the physical urban form and socio- political dynamics shaping risk. Eventually, addressing heat risk in Indian cities requires a t understanding of how urban form design the heat risk, making it essential to integrate spatial and morphological analysis into heat resilience policies and design practices (Yao et al., 2025)

The main problem addressed of study is the escalating heat stress in India's rapidly urbanizing cities, where dense development patterns intensify local temperatures, elevate health risks, and increase energy demand. Where national initiatives such as the India Cooling Action Plan (2019) advocate passive cooling measures and climate-responsive methods, and their on-ground adoption remains restricted. Moreover, there is insufficient empirical evidence on how specific urban neighborhood layouts influence microclimate conditions and localized heat stress. This gap highlights the need for research on urban form typologies (UFTs) as a foundation for climate adaptation, heat mitigation, and resilience planning.

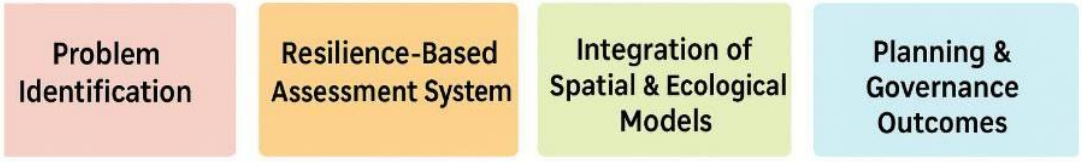


Figure 2 Assessing Urban resilience-based assessment Source: Adapted from Cheng et al. (2023), Urban Heat

1. Development of a Resilience-Based Assessment System:

A new urban resilience framework was formulated using the adaptation–resistance response model, integrating exposure, hazard, and vulnerability to provide a more all-inclusive assessment of urban heat risks. This approach overcomes the limitations of conventional risk assessments, which often fail to account for the dynamic ability of cities to adjust, absorb, and recover from heat. (Holling, 1973; Uddin et al., 2020; Cheng et al., 2023). Study approach addresses the limitations of traditional risk assessments that overlook the dynamic capacity of cities to adapt and recover from heat stress refer *Figure 1*.

2. Integration of Spatial and Ecological Models:

Study incorporates the Minimum Cumulative Resistance (MCR) model from landscape ecology and Landsat 8 remote sensing data to spatially identify heat hotspots and quantify the mitigating role of resilience in heat propagation (Aguilar-Barajas et al., 2019; Liu et al., 2023) integration allows a fine-scale assessment of heat resilience within diverse urban form typologies. (Akbari & Sharifi, 2024)

3. Guidance for Planning and Governance:

The proposed framework supports resilience zoning and guides urban planning strategies focused on heat-risk mitigation and sustainable urban development, particularly in rapidly growing regions or cities (Tran et al., 2017; Sanchez Rodriguez et al., 2018; Wang et al., 2018). It underscores the need for proactive adaptation measures and strong governance practices that align with broader sustainable development goals.

1.3 Need of the Study:

Rapid Urbanization and the Increasing Effects of Climate Change have led to Urban Areas facing Extreme Heat. Therefore, the importance of improving Resilience and developing Adaptable Planning Strategies will be a direct consequence of the Rising.

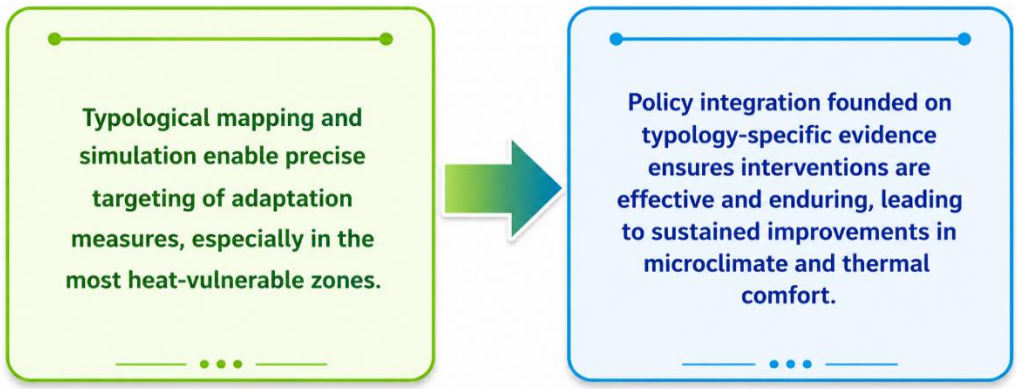


Figure 3: Typological mapping and policy integration framework *Source :- Author's compilation.*

Intensity of Urban Heat. Because the layout of both Structures and Streets (Urban Form) determines how Buildings and Open Spaces fit together within a Community, it impacts the local Microclimate of that Community. How Street Widths, Building Heights, Vegetation Density and Open Space Distribution affect both the Flow of Air, Shade and

Surface Heat Storage, determines the level of Impact for the Urban Heat Island Effect experienced. Different Urban Form Typologies allow for the Identification of Neighborhood Configurations (e.g., Higher Greenery Density; Lower Building Density; More Spread Out) that offer Optimal Performance in terms of Reducing Heat Stress. These Findings provide the basis for Implementing Evidence-based Intervention Strategies; Expanding Shade Areas; Creating Reflective Material Surfaces; and Enhancing Green Infrastructure in Heat-vulnerable Areas. The Research conducted in this area is intended to support Climate Responsive Urban Planning; Promote Public Health through Improved Quality of Life; and Assist with Long-term Environmental Sustainability.

A new urban resilience framework was developed from the adaptation-resistance response model, holistically incorporating exposure, hazard, and vulnerability to provide a more comprehensive measure of urban heat risks. This provides a step beyond the limits of conventional risk assessments that traditionally do not consider the dynamic capability of cities to adapt, absorb, and recover from heat. (Ishak et al., 2025).

The *Figure 3* shows it understanding neighborhood typologies can directly support more effective heat-adaptation planning. The first part emphasizes that detailed typological mapping and simulation help identify which areas face the highest heat vulnerability. Analyzing built form, vegetation, and surface characteristics, planners can focus adaptation measures exactly where they are most needed. Part highlights that when this typology-based knowledge is incorporated into policy, the resulting interventions become more reliable and long-lasting. Such evidence-driven decision-making leads to meaningful improvements in local microclimates and enhances thermal comfort for residents.

By more factors such as vegetation, building density, and surface materials, urban planners can target adaptation measures to the areas that need them most. Approach emphasizes that when knowledge of different neighborhood typologies is integrated into policy and planning, the resulting interventions are more effective and resilient. Implementing or integrating strategies methods based on this evidence ensures that local microclimates are improved, heat accumulation is less, and residents experience enhanced thermal comfort in their daily lives.

It can begin to target their adaptation efforts to appropriate locations based on information such as the amount of vegetation cover, the density of buildings, and the types of surfaces surrounding a community. This demonstrates that incorporating knowledge about the types of communities that exist within an area into your planning and policy framework creates more effective, contextually relevant, and resilient solutions. Evidence-based strategies, thus, create microclimates that are cooler in urban settings and keep heat build-up down. In addition, these strategies will help to enhance the comfort levels of residents through improved thermal comfort.

1.4 Title

Evaluating heat risk in urban areas: A Case study of Indore City

1.5 Aim

To evaluate heat risk in urban typologies and formulate heat risk strategies for the city of Indore

1.6 Objectives

Objectives of the Study

1. Classify and map urban form typologies.
2. Identify urban heat hotspots using LST.
3. Examine the link between urban form typology parameters and heat risk hotspot.
4. Develop heat-resilient design strategies and planning guidelines.

Objective 1: Classify and map urban form typologies.

The first objective of the study is to classify and map different urban form typologies using the WUDAPT framework and Local Climate Zone (LCZ) approach. This objective focuses on understanding the spatial characteristics of the built environment based on factors such as building height, building density, land use pattern, surface materials, and vegetation cover. The LCZ classification helps in identifying different

urban areas such as compact residential zones, industrial areas, commercial spaces, open lands, and vegetated regions. Mapping these urban forms provides a better understanding of how different physical characteristics of the city influence local climatic conditions and thermal behavior.

Objective 2: Identify urban heat hotspots using LST

The second objective is to analyses Land Surface Temperature (LST) patterns using GIS and remote sensing techniques in order to identify urban heat hotspot and cold spot areas within the study area. Satellite thermal data is used to study temperature variations across different parts of the city. Areas with higher temperatures are identified as heat hotspots, while comparatively cooler areas are identified as cold spots. This analysis helps in understanding which areas experience more heat stress and how temperature is distributed spatially within the urban environment.

Objective 3: Examine the link between urban form typology parameters and heat risk hotspot.

The third objective is to examine the relationship between Local Climate Zones (LCZs), urban morphology, and Land Surface Temperature (LST) variations. Different urban forms such as dense built-up areas, open layouts, industrial zones, and vegetated regions influence temperature differently. This objective focuses on understanding how factors such as building arrangement, density, street pattern, and land cover affect urban thermal conditions. By comparing LST values across different LCZ classes, the study helps in identifying how urban form contributes to higher or lower temperatures in the city.

Objective 4: Develop heat-resilient design strategies and planning guidelines.
and SVF on UHI

The fourth objective focuses on evaluating the influence of built-up density, vegetation cover, impervious surfaces, Sky View Factor (SVF), and urban morphology on the Urban Heat Island (UHI) effect and urban thermal stress. Dense built-up areas with concrete structures, asphalt roads, and less vegetation tend to absorb and store more heat, leading to higher temperatures. On the other hand, green spaces and open areas help in reducing heat and improving thermal comfort. The Sky View Factor (SVF) is also studied to understand how openness and building arrangement influence sunlight

exposure, airflow, and heat retention within urban areas. This objective helps in identifying the major factors responsible for urban heat accumulation.

Objective 5: Develop heat-resilient design strategies and planning guidelines

The final objective is to propose heat-resilient urban design strategies and climate-responsive planning guidelines for reducing urban heat risk and improving thermal comfort in the study area. Based on the results of the study, suitable planning and design measures are suggested to reduce the Urban Heat Island (UHI) effect and improve the urban thermal environment. These strategies may include increasing urban green spaces, promoting cool roofs and reflective materials, improving street shading and ventilation, and encouraging sustainable urban planning practices. The study also aims to support the inclusion of heat-resilient measures in urban planning frameworks and Development Control Regulations (DCR) for creating healthier and more climate-responsive urban areas

1.7 Methodology

Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework was adopted to guide the analysis & screening of studies used in this review. Applying the PRISMA approach enhances clarity, reliability, and transparency of the research process by providing a standardized method for identifying, evaluating, and selecting relevant literature of this. Following the steps outlined by Mohamed Shaffril et al., review process consisted of four key stages of identification, screening, eligibility, and inclusion. These stages, the authors systematically located, assessed, and synthesized studies related to heat resilience to produce the comprehensive and credible literature review.

This analysis draws on peer-reviewed articles published in the Scopus database up until December 2025, as Scopus is known for providing access to a comprehensive set of peer-reviewed journals covering a broad scope of high-quality, internationally recognized research across many disciplines. However, because Scopus is not comprehensive and excludes certain types of research, including articles from smaller publishers and country-specific databases, it may miss out on other types of research that may be essential to achieving an informed conclusion regarding urban projects. As

such, these limitations need to be considered when conducting the systematic review. To lessen these limitations, a comprehensive search strategy was designed and the number of published papers, through systematic reviews, involved in generating a large amount of data to provide depth and reliability was analyzed. The high number of reputable urban climate, environmental planning, resilience, and geospatial analysis journals in Scopus was an important factor that contributed to the reliability and importance of the research chosen for this study.

For this review, articles were retrieved using targeted study search keywords relevant to the research topic. The search string was adapted specifically for **Evaluating heat risk in urban areas: A case study of Indore city**, as follows: analysis focuses on peer-reviewed scientific publications indexed in the Scopus database up to December 2025. Scopus was chosen due to its wide range coverage of high- quality international level research and its strong influence across multiple disciplines. Nonetheless, relying solely on Scopus is acknowledged as a limitation, as relevant studies from other databases or other platforms may not have been captured. Although extensive, Scopus does not index all global research outputs, which may have resulted in the exclusion of potentially valuable contributions from outside the database.

To address this are limitation, a thorough and systematic search strategy was employed, and a substantial dataset of publications was analyzed to ensure depth and accuracy. Scopus includes a significant number of influential journals in this fields of urban climate, environmental planning, resilience studies, and geospatial analysis, supporting the robustness of the selected literature.

TITLE-ABS-KEY:

(“urban heat resilience” OR “heat risk” OR “urban heat island” OR “UHI mitigation” OR “thermal comfort” OR “neighborhood heat exposure” OR “urban microclimate” OR “heat adaptation”)

AND

(“urban morphology” OR “urban form” OR “neighborhood design” OR “built environment” OR “green infrastructure” OR “climate-resilient planning”)

("Local Climate Zone" OR "LCZ" OR "WUDAPT" OR "urban morphology classification" OR "urban form typology" OR "urban spatial structure" OR "built density" OR "urban canopy characteristics")
AND
("Land Surface Temperature" OR "LST" OR "Urban Heat Island" OR "UHI" OR "surface urban heat island" OR "urban thermal environment" OR "thermal hotspot" OR "urban heat exposure")
AND
("vegetation cover" OR "green space" OR "impervious surface" OR "Sky View Factor" OR "SVF" OR "urban geometry" OR "microclimate" OR "urban climate")
AND
("heat mitigation" OR "heat-resilient design" OR "climate-responsive planning" OR "urban cooling strategies" OR "sustainable neighborhood planning" OR "climate adaptation")

This structured search supports the systematic identification of studies investigating the relationships between urban morphology, LCZ classification, thermal patterns, and environmental factors influencing urban heat dynamics, while also exploring heat-resilient urban design and planning strategies.

- **METHODOLOGY**

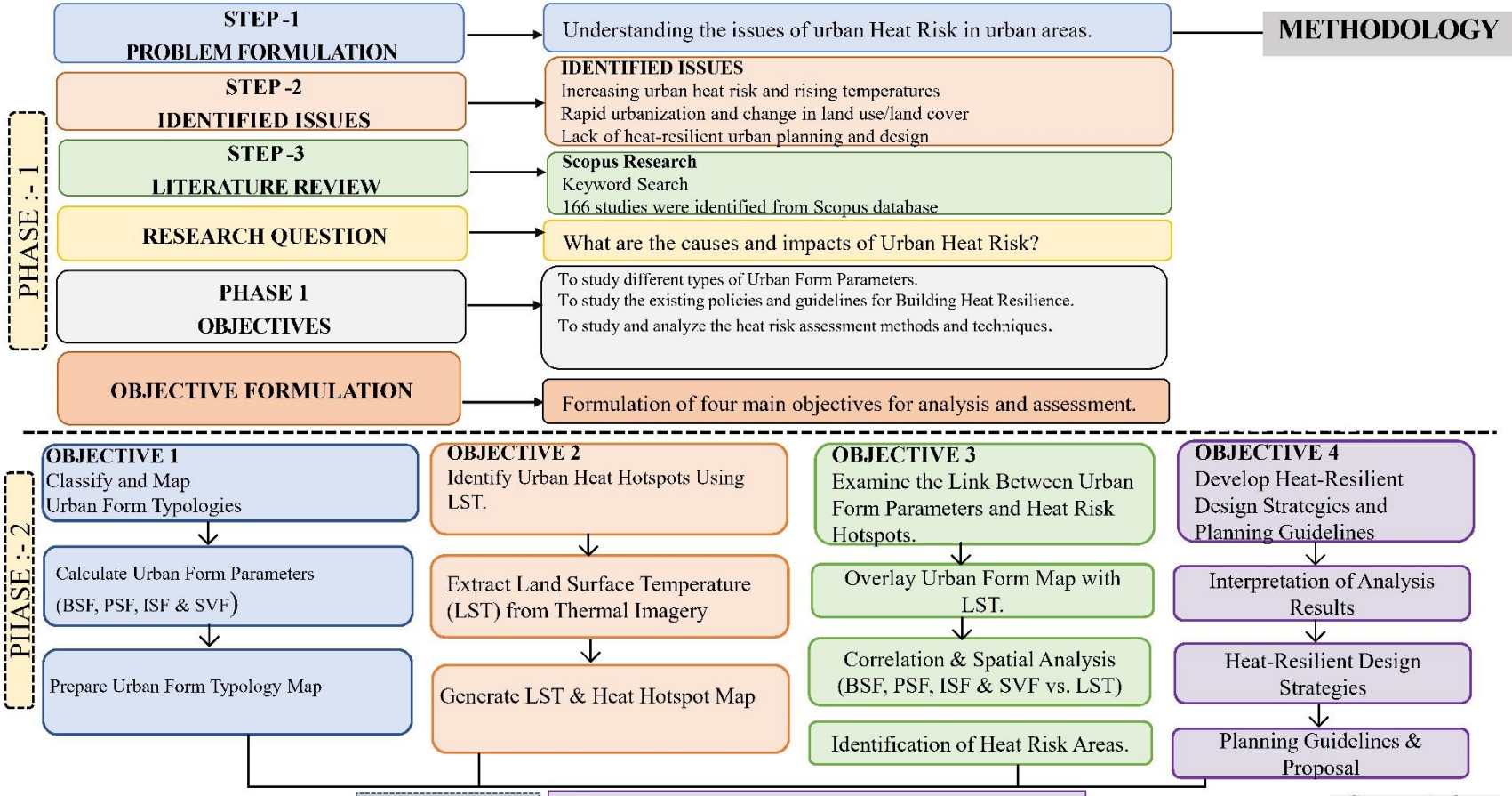


Figure 4Methodology for Phase-I & II

Source: author

1.8 Scope

1. Classify urban form typologies using the LCZ approach.
2. Identify urban heat hotspots using LST data.
3. Examine the relationship between urban form parameters and heat risk.
4. Suggest heat-resilient planning and design strategies.

1.9 Limitations

1. The study is based on satellite-derived Land Surface Temperature (LST) data and selected urban form parameters (BSF, PSF, ISF, and SVF).
2. The analysis represents a specific study period and may not capture seasonal variations in temperature patterns.
3. Findings are limited to the selected study area and may not be directly applicable to other cities or regions.

Chapter-2
Literature Review

2.1 Literature Review: Urbanization, Climate Change, and Heat Stress

Rapid urbanization, as well as climate change, are placing more and more ecological stresses on urban areas. Cities are centers of social and economic development and as such, the pressures of urbanization combined with the increasing impacts of climate change will lead to an increasing number of "climate risks" that cities will be exposed to rising temperatures and increasing amounts of heat stress. The Urban Heat Island Effect (UHI) is one of the most visible effects of urban vulnerability where Urban Areas can have 5°C higher temperatures than surrounding Rural Areas, which creates a thermal imbalance with Urban Areas needing to use more energy for cooling, have worse Air Quality and create health risks to vulnerable populations. There are many other challenges urban areas face that must be addressed to improve Heat Resiliency. (Masha et al., 2025)

Urban resilience' means urban centers' ability to ensure their most crucial functioning (or basic operations) continues without interruption during or after a disruption of service(s). Urban areas must be able to use current knowledge about climatic change developing over time, adapt as appropriate to the environment changing with time and establish themselves as CCRC's Climate Change Resilient Cities (CCRC's).The response from urban and metropolitan directors is to better define how urban forms impact thermal properties in networks using analytical methods that provide data through geographic information systems (GIS) and advance the ability for urban planners and managers to better position their government's resources to be prepared to maintain urban resilience at a neighborhood level. Using this expanded knowledge will better position urban managers to respond to disruptions in urban thermal performance. (Kiberet et al., 2025)

2.1.1 Conceptualizing Urban Heat Resilience and its Drivers

The Interaction of Urban Morphology and Thermal Environment Urban morphology, this encompasses the geometric shape, density, and functional layout of buildings, that

deeply governs the thermal environment and carbon emissions in cities. The relationship is not merely linear; complex, cooperative interactions exist between carbon emissions and air temperature, which are more broadly framed as "heat-carbon" dynamics. (Masha et al., 2025) Research on multidimensional urban morphology classifies influencing factors into two-dimensional (2D)

The Relationship Between Heat and Urban Form (Heat-Cars) Urban Morphology: Urban morphology provides the geometric configuration, density, and function of the building structure and therefore is one of the primary determining factors of the urban thermal environment and carbon emissions within cities. However, this relationship is not just a straight line but has a complex and cooperative interaction of the heat-carbon dynamics (Masha et.al., 2025). Research studies concerning the multidimensional urban morphology have classified the factors affecting the urban form into 2D (two-dimensional) and 3D (three-dimensional). Two-dimensional indicators such as Building Coverage Ratio (BCR) and the proportion of impervious areas affect the surface energy balance directly. In densely constructed areas, the ability of the air to cool down is impeded by the high heat capacity of buildings, which causes the elevation of air temperature through the high heat capacity of the building stock and reduction of the ability to cool through ventilation.

AH and building shape, which modulate the urban thermal environment by changing shadow distribution and airflow efficiency. For example, a reduction of 52.3-61.7% in lifecycle carbon emission of buildings has been estimated through the optimization of urban morphology. Compact urban layouts minimize carbon emissions due to reduced distances in commutes and transportation energy consumption.

2.1.2 Quantifying the Heat-Carbon Synergy

Carbon emissions and air temperature display a marked seasonal effect. Specifically, in the Xiong' an New Area of China, there is a strong positive correlation between the two during summer months. In the summer, as air temperature increases, so does the demand for energy to cool buildings, producing additional waste heat, which creates an amplifying feedback loop that leads to additional local warming. However, research shows that in winter, the correlation becomes very weak and negative. Thus, the spatial correlation of "high emissions and low temperatures" is likely caused by high levels of

carbon emissions produced by heating during periods when air temperatures are at their lowest, which creates a weak, unidirectional effect from carbon emissions toward increasing air temperature. (Sheng et al., 2025)

Specific morphological parameters exhibit varied effects across seasons:

- In summer, the Building Coverage Ratio (BCR) indirectly shows a positive effect on air temperature by increasing the Spatial Crowding Index (SCI).
- In contrast, in autumn and winter, the BCR exhibits a direct negative effect on the air temperature, suggesting that the enhanced shading effect of high building density may lead to a decrease in local air temperature during colder months.

The dynamic relationship highlights the challenge for urban planners, as the same morphological parameter can yield different, or even reverse, environmental benefits depending on the season, complicating efforts to accomplish comfortable thermal environments and low-carbon communities simultaneously (Hu, 2025)

2.1.3 Approaches for Evaluating Heat Resilience

Evaluating heat resilience necessitates sophisticated tools capable of capturing the complex spatial, morphological, and temporal dynamics of urban systems.

Geospatial Assessment Frameworks

This complexity of CCRC demands assessment frameworks that acquire multiple dimensions, including infrastructure, ecosystems, socio-economic structures, and governance mechanisms. A comprehensive CCRC assessment system must integrate dimensions such as economic resilience, social resilience, environmental resilience, and management. System requires multi-source heterogeneous data, utilizing additional indicators from existing benchmarks like the Rockefeller Foundation's 100RC framework and ISO 37123.

On a process level, urban resilience development can be divided into stages: resistance, recovery, adaptation, and transformation to analyze the process of urban resilience development, particularly during crises like the COVID-19 pandemic, emphasizing that

building resilient cities requires locally adapted strategies that foster long-term resilience. High-Resolution Data and Modeling and analysis of this resolution emission.

Acknowledge Traditional analyses of urban carbon emissions often rely on Original Mixed Night-time Lights (OMNL), which aggregates light intensity across various land uses, leading to inaccuracies. A novel methodological framework has been developed to estimate high-resolution emissions using Functionally-Filtered Night-time Lights (FNL), combine remotely sensed human activities (like LJ1-01 satellite data) are social media data (Points of Interest or POI data). FNL extraction focuses on isolating the residential lighting contributions by calculating functional weights for specific land-use types using statistical methods like Fisher's exact testing. This refinement significantly improves the monitoring and understanding of urban emission dynamics by reducing the identification of excessive value points in carbon hotspots compared to OMNL. FNL is valuable for micro-level analysis because data contains semantic information that remote sensing alone cannot extract, which is highly beneficial for studying settlement emissions.

2.1.4. Strategies and Policy Implications for Enhancing Neighborhood

Heat Resilience multiple criteria based on Urban Planning and Geospatial Technology such as Geographic Information System (GIS) and the Analytic Hierarchy Process (AHP), factors evaluated to determine Land Suitability include: Land Use, Land Cover (LULC), Accessibility to Roads, Streams, Soil Quality, Slope Suitability, Population Density, and to Historical Landmarks. Areas and Zones with High Population Density, Green Spaces (UGS), whether developed or established, are often the most desirable locations for UGS Development as these areas currently have limited vegetation, are generally densely constructed urban settings, and can assist in reducing heat stress while enhancing the overall quality of life of the individuals that live there. Additionally, heavily built-up areas or cultivated land is typically not ideal for UGS Development because of land use and space limitations**.** Governing Resilience and Policy Pathways.

Evaluating heat resilience demands highly sophisticated tools, which have to capture complex spatial, morphological, and temporal dynamics of urban systems.

2.1.5 Geospatial Assessment Frameworks

This complexity of CCRCs demands assessment frameworks that acquire several dimensions, including infrastructures, ecosystems, socio-economic structures, and governance mechanisms. Such a comprehensive CCRC assessment system should bring together dimensions like economic

It targets resilience, social resilience, environmental resilience, and management. The system necessitates multi-source heterogeneous data, using more indicators from already existing benchmarks like the Rockefeller Foundation's 100RC framework and initiative indicate that the program successfully advanced CCRC objectives, particularly in cities with widely accepted emergency management institutions. Still, the initiative has also been critiqued for insufficiently accounting for the diverse geographical, economic, social, and cultural conditions of individual cities, highlighting the need for more locally tailored resilience pathways. (Sheng et al., 2025)

Policy recommendations for optimizing urban morphology to mitigate UHI and reduce carbon emissions emphasize prioritizing measures in summer when the heat-carbon synergy is strongest. Specific strategies include:

I. Implementing strict building density controls in newly developed areas to curb carbon emissions and thermal mass accumulation.

II. Establishing building compactness ratios as mandatory design standards, favoring simple geometric forms to minimize solar heat gain and cooling energy demand.

III. Optimizing urban ventilation through the preservation of summer wind corridors and decentralized placement of high-rise clusters to facilitate heat dissipation.

Evaluating urban resilience also required understanding public perspectives. Studies leverage data from public feedback channels to formulate indices reflecting community perceptions and government responses to the climate risks, including extreme heat. more datasets provide valuable insights for assessing the effectiveness of local climate policies are, enhancing disaster management capacity, and evaluating initiatives like "Resilient City" programs. (Sharmin & Chappell, 2025)

Assessing and enhancing heat resilience in urban neighborhoods is a complicated challenge that intersects the climate science, urban design, and governance. role rely on precise, high-resolution assessment tools combine with adaptive, context-specific policies that optimize urban morphology and expand green infrastructure to disrupt the positive feedback cycle between heat and carbon emissions method translates theoretical concepts into actionable remedies guiding sustainable and climate-resilient urban development. (Masha et al., 2025)

It is difficult to improve the resilience of urban neighborhoods to extreme heat due to the sustainability and complexity of utilizing current climate science, urban planning, and policies to reach this goal. Success will depend on the effective use of scalable, accurate, valid, high-resolution assessment tools; and creating adaptive, context-sensitive policies that optimize urban form and increase green infrastructure. This approach will disrupt the self-perpetuating relationship between heat and greenhouse gas emissions and will transform many concepts previously viewed conceptually to practical implementation strategies for climate-resilient and sustainable urban development. Using multiple criteria components of Urban Planning and Geospatial Technologies, including Geographic Information Systems (GIS) and Analytic Hierarchy Process (AHP), Land Suitability Factors are evaluated based on the following factors; Land Use, Land Cover (LULC), Accessibility to Roads, Streams, Soil Quality, Slope Suitability, Population Density and Historical Landmarks. Populated areas and Zones with High Population Density, and Urban Green Spaces (UGS) are potential locations for the establishment of UGS Development. Many of these areas have sparse vegetative cover, are heavily constructed urban environments, and can assist with heat stress and improve the overall quality of life for the people living there, therefore they are desirable for this purpose. Furthermore, highly populated and developed areas, or cultivated land, are generally characterized by less vegetation and higher rates of air pollution.

Table 1 Summary of Literature on Heat Resilience Assessment in Urban Typologies

S.No.	Source (Author, Year)	Topic / Study Area	Methodology	Key Findings	Main Parameters	Research Gaps
1	Shafeeq Ahame d & Md Asif (2018)	Floods + UHI links (general)	Systematic 3-component: Hazard / Exposure / Vulnerabilit y	Encroachment, poor drainage, and UHI amplify flood impacts	Rainfall intensity, slope, drainage density, impervious cover	Limited real-time monitoring; dataset integration needed
2	Y. P. Solanki et al. (2024)	Flood risk mapping	GIS + AHP multi-criteria spatial overlay	Identifies riverine high-risk zones for emergency planning	Precipitation, elevation, flow accumulation	Dynamic validation; stakeholder engagement gaps
3	P. Tomar et al. (2021)	Catchment flooding and heat-stress links	Integrated GIS–RS, gauge–rainfall correlation, field validation	Urban congestion worsens thermal stress during flood events	Precipitation, catchment area, elevation, discharge	Socio-economic integration missing; limited real-time data
4	R. Devi et al. (2025)	Flood assessment & urban exposure	FVI, HEC-RAS, XGBoost ML, building overlay	Impervious surfaces increase heat retention + flood impacts	Flood depth, building height, land cover, population exposure	Long-term validation; socio-economic datasets needed
5	S. Kumar & N. V. Uma Mahesh (2025)	Stormwater + LID effectivenes s	PCSWMM hydrodynam ic modeling, LID scenarios	LID reduces peak flows (8–16%); supports adaptive design	Rainfall frequency, infiltration rate, impervious ratio	Maintenance , cost-benefit, scalability concerns
6	Schöneberg er et al. (2025)	High-density subtropical urban form (Hong Kong)	LCZ mapping (k-means++), UAV, field thermal measuremen ts	ENVI-met output improves with empirical albedo & cloud parameters	MRT, SW flux, albedo, LST, SVF	Challenges simulating radiative fluxes under clouds & shading
7	Sheng et al. (2025)	Cold-season thermal stress (Dalian)	LCZ mapping, UAV, portable weather stations	Dense LCZs show worst winter comfort; vegetated LCZs improve cooling	UTCI, PET, LST, wind, solar radiation	Need integrated LST + thermal indices for urban planning
8	Ramsay et al. (2021)	Chronic heat stress in informal settlements (tropics)	In-situ sensors (iButtons), WBGT/TW analysis, scenario downscaling	WBGT crosses safe work thresholds; weather stations underestimate heat	Temp, RH, WBGT, TW, solar radiation, wind	Need community-level mitigation; household-scale datasets

9	Sharmin & Chappell (2025)	UHI changes using LCZ (Dhaka)	LCZ mapping + Landsat LST + NDVI; MDC analysis	Dense built areas ~1.2°C warmer; vegetation reduces LST by ~2.4°C	LST, NDVI, LCZ class, seasonal variation	Need LCZ-sensitive urban planning; transitions in urban form
10	Siqi Jia et al. (2025)	Pedestrian spaces & heat stress (Hong Kong)	SVF analysis, sensors, neural networks	74.8% of areas show strong–extreme heat stress; SVF strongly correlated	Ta, Tmrt, HVA, SVF, green/impervious %	Improve Tmrt estimation; more field-based validation
11	O. Abedrabboh et al. (2025)	Hot-arid cities (global)	Review: ENVI-met, WRF, RS synthesis	Daytime cool islands common; trees most effective GI strategy	LST, Ta, MRT, NDVI, albedo, SVF	More empirical studies in BWh regions; cross-scale validation
12	Peer Schöneberger et al. (2025)	MRT in street canyons (Hong Kong)	Calibrated ENVI-met + radiometers, validation metrics	MRT RMSE ≈ 2.62 K; better SW flux accuracy after calibration	MRT, Ta, SW flux, albedo, emissivity, SVF	Need modeling of micro-reflections; cloud datasets lacking
13	Elham Bahadori et al. (2025)	Urban heat / UHI (global review)	UCM–BEM integrated review of urban models	Green roofs, cool materials, and morphology reduce UHI	Ta, LST, anthropogenic heat, geometry, HVAC loads	Limited multi-scale validation; uncertainty quantification
14	Fazal Akbar Akbari & Ayyoob Sharifi (2024)	Informal settlements (Kabul)	LCZ subclasses + Landsat LST analysis	Low-rise/lightweight LCZ types show highest LST	LST, ABH, PSF, impervious fraction, SVF	Need LCZ thresholds for informal settlements; sub-LCZ classes
15	Sun et al. (2025)	Climate risk & government response (China)	Word2Vec dictionaries, climate-risk text indices (2011–23)	Public sentiment and government response indices guide adaptation	Public sentiment vocab, climate exposure vocab, response metrics	Transferability to other regions; integration with physical risk

2.2 Urban Morphology and Thermal Conditions: A Review of Typologies

Research on heat resilience in urban neighborhoods the more significant influence of urban form typologies on thermal conditions and adaptation potential. Studies on compact, high-density built environments consistently show that such forms exacerbate the Urban Heat Island (UHI) effect due to restricted ventilation, narrow street canyons,

and high thermal storage. Oke (1988) was among the first to link compact urban morphology with heat accumulation, while Santamouris (2015), in a comparative analysis of Asian and Australian cities, demonstrated that dense megacities often record some of the highest UHI intensities, creating major challenges for urban heat resilience (Banerjee et al., 2022).

The results of different research studies show that Urban Heat Island Effect has been created by hot urban areas and that to reduce Urban Heat Islands and Thermal Comfort issues it is necessary to find ways to create and maintain Urban Green Areas as low-rise and open forms of Urban Design can increase the amount of airflow and decrease the effect of heat stress. In a study on outdoor thermal comfort for tropical cities Johanssen & Emmanuel 2006, found that climate-sensitive urban design is an effective means of mitigating the Urban Heat Island Effect. Urban Green Areas and improved Airflow Corridors lower localized warming, so by creating Urban Green Areas and improved Airflow Corridors to take full advantage of air and vegetation we can create more resilient neighborhood micro climates. In addition to studying urban heat islands mitigation, there has been considerable research done on Urban Green Areas and the benefits they provide; namely, temperature reductions due to surface & Air temperature, Air Quality and Human Health. (2010)

Significant research has also focused on green-integrated urban forms, where more vegetation and water bodies are embedded within the built environment. Bowler et align a systematic review, found the urban greenery substantially reduces both surface and air temperatures, because enhancing heat resilience. Similarly, Ng et al. (2012) documented cooling effects of 2–3°C in vegetated areas of high-density Hong Kong, demonstrating the effectiveness of green infrastructure even in compact urban contexts.

Mixed or hybrid urban typologies that combine multiple design methods are have also been examined in heat-related study. Emmanuel (2005) emphasized the role of climate-sensitive urban design in tropical regions, showing that variations in building height, mixed land uses, and integrated green spaces can improve their thermal comfort by optimizing shading, enhancing ventilation, and strengthening landscape functions. His work highlights that thoughtfully planned hybrid layouts can modify microclimates more effectively and reduce heat stress across diverse neighborhood settings (Banerjee et al., 2022).

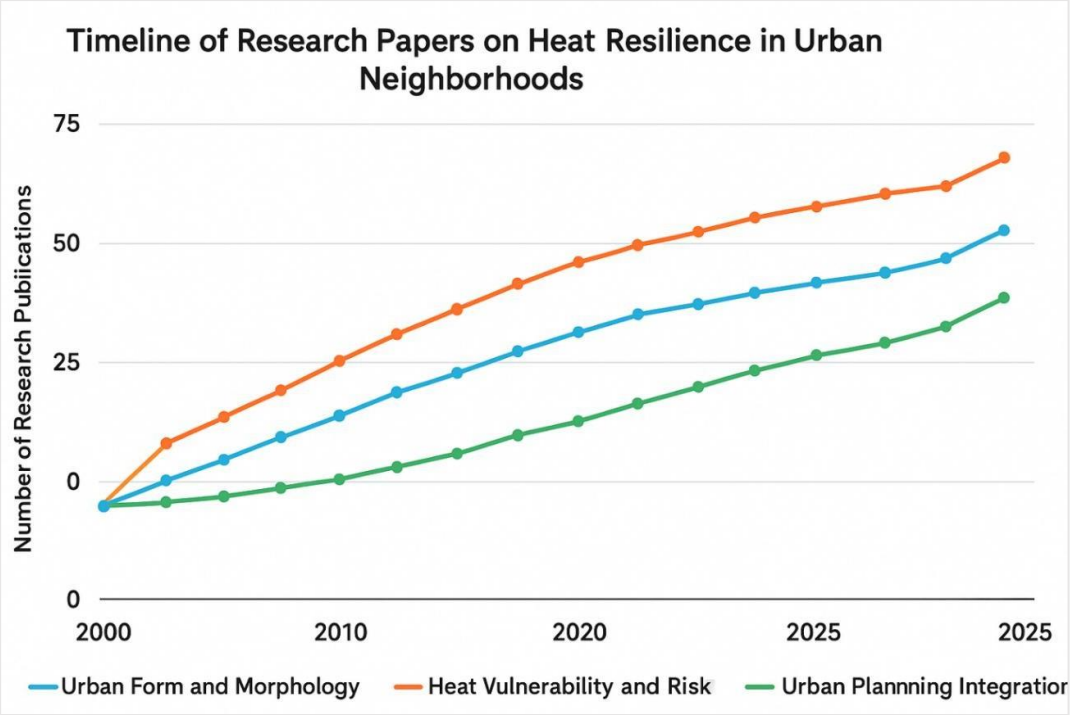


Figure 5 According to literature papers the Timeline and their form typologies *Source: Author's*

The graph shows how research on heat resilience in urban neighborhoods has grown from 2000 to 2025 across three major themes.

This timeline of research publications on heat resilience in urban neighborhoods, spanning from 2000 to 2025, reveals distinct and evolving thematic priorities within the field. The research area focusing on Heat Vulnerability and Risk has consistently driven the field, maintaining the highest cumulative number of publications throughout the period, reaching nearly. This emphasis underscores the foundational importance of identifying and quantifying heat exposure and susceptibility in urban populations. Research on Urban Form and Morphology, which examines the influence of city design on heat, it occupies the second tier, showing a steady, linear growth to over 50 publications. However, the theme of Urban Planning Integration lags significantly, reflecting a relatively slower and later development, reaching only about 38 papers. suggestions that while there is substantial knowledge of regarding urban heat risks and physical mitigation measures, the body of work on translating these findings into implementable, integrated policy and planning practice is still emerging, particularly evidenced by the steeper curve in this theme over the most recent years. Trends highlight the critical need for the future research to focus on practical implementation and policy integration to effectively build heat-resilient urban environments.

Urban Form and Morphology: This theme has the second highest publication count with over 50 papers by 2025 and represents the largest area of research in physical mitigation. Physical mitigation research studies examine how a city's physical characteristics (density of buildings, geometry of streets) are causally related to the thermal environment within the city. Researchers provide data-driven recommendations on how to cool cities through the use of design strategies (refer to Figure 4).

Heat Vulnerability and Risk: This area has consistently been the dominant focus of research, reflecting the foundational need to quantify the problem. Its high and rapidly growing cumulative publication count (nearly 70 papers by 2025) indicates that the primary scholarly effort has been directed towards identifying and assessing which populations, areas, and demographic groups are most susceptible to adverse health outcomes from urban heat.

Urban Planning Integration: In recent years, this area has experienced the fastest growth, going from a few papers to nearly 40 by 2025, indicating a developing field, which will now become more established by transitioning from defining problems and the theory of planning to addressing how to implement policies. See Figure 4. Research here is essential to convert the understanding of vulnerabilities and design strategies into disciplinary planning regulations and effective governmental actions that can be executed.

Research in urban heat resilience, tracked across the three categories, has established that high temperatures in cities now present one of the major threats to public health, particularly for sensitive populations. Studies successfully quantify the Urban Heat Island effect and validate the effectiveness of physical interventions such as increasing green infrastructure and using cool, reflective materials in an effort to reduce surface temperatures. The cumulative outcome, therefore, is a robust evidence base and a set of clear policy recommendations that demand cities go beyond mere risk assessment to actual integration of heat mitigation into long-term urban planning, with strong emphasis on equity and implementation. (Song & Lu, 2025)

The Urban and Regional Heat Risk Assessments consider a broad range of interrelated parameters to help generate heat exposure and vulnerability assessments to Extreme

Heat Events and a community's ability to adapt. Thermal intensity is measured using Land Surface Temperature (LST) and Air Temperature as direct measures of the intensity of thermal conditions at a given point in time, while multiple indicators including Heatwave Frequency, Duration and Intensity capture the dynamic and episodic nature of hazardous heat conditions over time. High Relative Humidity is critical when considering the effect of hot weather on the human body since it increases the potential for heat-related illnesses and increases the physiological impact of high air temperatures.

Research conducted on urban heat resilience, categorized by the three aforementioned categories, demonstrates that high urban temperature is a public health threat to vulnerable populations. The studies presented in this document demonstrate that the Urban Heat Island effect can be quantified throughout the cities studied, and that physical interventions such as increasing green infrastructure and using cool, reflective surfaces can effectively reduce on-site surface temperatures. Therefore, the research conducted on urban heat resilience provides a comprehensive scientific foundation, as well as a clear set of policy recommendations that will lead to the integration of heat mitigation strategies into the long-term planning of cities while focusing on equity and implementation.

Population exposure measured through population density or the number of people in affected areas is a central factor in estimating potential impacts, particularly in cities where urban heat island effects elevate local temperatures. Demographic and socioeconomic characteristics, including age, gender, and income level, further shape heat sensitivity, with vulnerable groups such as the elderly, children, and low-income households facing higher risks.

Built environment factors, such as the presence of green space, dominant building materials, and the proportion of impervious surfaces, strongly influence the formation and mitigation of urban heat hotspots. Together, the parameters provide an overview understanding of heat risk and inform targeted strategies or methods for enhancing urban resilience.

Access to cooling infrastructure, such as air conditioning, public cooling centers, and shaded public areas, determines a community's capacity to cope with the heat events.

Adaptive capacity indicators also reflect the ability to respond, encompassing health infrastructure, socio-economic resilience, and the presence of social safety nets. Research gaps remain in integrating fine-scale health, socio-economic, and microclimate data, improving prediction of future risk zones, and developing actionable early-warning and intervention strategies tailored to diverse and vulnerable urban populations. (Sharmin & Chappell, 2025)

Research gaps in heat risk assessment persist across several dimensions. This remains a critical need to better integrate socio-economic and health datasets, improve typologies-scale microclimate modelling, and strengthen predictive analytics for early warnings and targeted interventions. The diversity of built environment conditions and exposure contexts further for more granular data and context-specific methodologies that can accurately capture local variations. Ensuring that these approaches prioritize and reach the most at-risk populations is essential for advancing urban heat resilience and safeguarding public health in an era of intensifying climate extremes.

A central priority for long-term resilience is promoting equity and sustainability. Community engagement and public–private partnerships play main role in fostering local ownership, ensuring the maintenance of interventions, and supporting continuous adaptation as environmental conditions evolve. Innovation in cooling measures from neighborhood-scale tree planting to the development of public cooling centers. Mapping vulnerable populations, investing in adaptive health and infrastructure, and delivering public awareness campaigns work in tandem to address disparities. By integrating nature-based, technological, and participatory methods, urban environments become better equipped to withstand, adapt to, and eventually thrive amid the growing risks brought by climate extremes.

These are standard published works that establish their contribution to climate-sensitive urban design, ecological planning, heat-resilient infrastructure, and community-based urbanism.

2.2.1 Importance of Urban Form in Shaping Heat Risk and Resilience in Indian Cities

Urban form plays a crucial role in shaping heat risk and resilience in Indian cities, as variations in building density, street layout, open spaces, and vegetation directly

influence local microclimates, heat exposure, and a neighborhood's capacity to cope with rising temperatures.

Most Indian cities still concentrate efficient infrastructure such as water supply, sewerage, and public transport within their urban cores, forcing peripheral and suburban areas to rely on fragmented and unplanned development. These peripheral neighborhoods often characterized by varying built-form typologies such as dense informal settlements, mid-rise housing clusters, or sparsely built layouts respond very differently to extreme temperatures due to their material composition, density, vegetation cover, and surface characteristics.

Indian cities are getting hotter because of rapid urban growth, causing more health problems and higher energy use. Although the India Cooling Action Plan (2019) suggests ways to control heat, like that using passive design and cool roofs, these ideas are hard to put into practice in local neighborhoods. This main issue is that there is not enough clear knowledge about how different neighborhood pattern of layouts affect heat. Understanding this is needed to make better plans.

Therefore, understanding how different urban form typologies shape heat resilience becomes critical for climate-adaptive urban planning. While past studies have extensively examined suburbanization and sprawl in India, very less have evaluated how this spatial redistribution of population and built form generate into thermal risk or resilience at the neighborhood scale. (M. Wang, Dong, et al., 2025).

Urban form plays a critical role in shaping heat risk and resilience in Indian cities by influencing how heat is absorbed, stored, and released within the built environment. The arrangement of buildings, street networks, and open spaces directly affects airflow, shading, and surface temperatures, thereby determining the intensity of the urban heat island effect. In many rapidly growing Indian cities, unplanned and compact development often concentrated in informal settlements limits ventilation and reduces access to green spaces, heightening heat exposure and vulnerability for residents. In contrast, neighborhoods with more organized layouts, greater vegetation cover, and adequate open spaces benefit from improved microclimates and naturally moderated temperatures.

The wide range of urban morphologies in India from dense historic cores to sprawling informal settlements and newly planned developments creates localized variations in heat stress. This underscores the importance of conducting assessments at the neighborhood scale, where built form characteristics intersect with socio-economic conditions to influence both vulnerability and adaptive capacity. Nature-based solutions, such as increasing tree cover, restoring permeable surfaces, and enhancing wind corridors, are essential for mitigating heat in existing urban areas.

The built environment and organizational layout of cities in India plays an important role in determining how heat risk patterns occur and how cities are able to recover from heat risks. Approaches to planning that combine the integrated planning of urban morphology, infrastructure, and social equity issues will be essential for establishing long-term, sustainable urban forms that can also provide resilience against increasing heat threats. In terms of climate adaptation and resiliency, it will be critical to incorporate urban form into adaptation and resiliency planning frameworks as temperatures continue to rise. As stated previously, an integrated approach combining urban form optimization with infrastructure improvement and social equity considerations will provide cities with tools to mitigate heat risk while at the same time continuing to protect their most vulnerable citizens. Finally, the spatial structure and design of a city and its built environment are key determinants of how heat risk patterns develop across the city, and therefore must be considered when developing an integrated planning process for a resilient and sustainable urban future.

2.2.2 Emerging Approaches in Assessing Urban Heat Resilience

The form of a city influences heat risk and resilience through the way that heat is absorbed, stored and released within the built environment. By influencing how air flows in and out of buildings as well as how much shade is provided to an area, urban form directly impacts the degree to which the Urban Heat Island Effect occurs. For many of the rapidly growing cities in India where the majority of the built form was created organically without planning (i.e. informal settlements) and due to the focus on compact city growth, the unplanned, compact nature of the built form restricts proper ventilation and limits residents from accessing green spaces, creating a higher level of heat exposure and vulnerability for residents. Conversely, organized combinations of built forms, greater amount of green vegetation, and adequate access to open spaces

allow residents to have more favorable microclimates and naturally modulate ambient temperatures. The range of urban morphologies across Indian cities, including dense historic cores, sprawling informal settlements and newly created planned developments, create localized urban heat stress variations. Therefore, assessments need to be performed at the neighborhood level, where built form characteristics of neighborhoods meet and intersect with the socio-economic realities of the residents, to determine both vulnerability and adaptive capacity. Urban greening practices and restoration of permeability (i.e. increasing tree cover) and wind corridors are a necessary part of reducing heat in existing urban areas. Consequently, the spatial arrangement and characteristics of all Indian cities'-built environments are the primary determinants of patterns of heat risk within that geography. (Schöneberger et al., 2025)

Different spatial configurations like that as compact, grid, sprawl, and radial urban forms—significantly shape solar radiation exposure, wind movement, shading, and heat storage, all of which influence local temperature patterns and energy use. Solar radiation exposure, wind behavior and movement, shading, and heat storage all relate to urban form. However, Urban Heat Island effect is intensified with Compact Urban Forms and Restricted Airflow and Trapped Heat, through adjacent buildings. Conversely, the greater dispersal of building footprint area and extended infrastructure network of an open or grid-style layout can increase energy requirements due to greater demand for heating and cooling. (Heris et al., 2020; Marey, 2025).

Land use and green cover also influence Urban Forms by regulating heat retention and humidity levels through Evapotranspiration. Mixed-use areas containing vegetation and water bodies provide cooling effects on the local microclimate and reduce energy consumption for cooling compared to areas that are predominantly covered by impermeable surfaces, as densely built areas tend to accumulate and retain heat. GIS-based research has consistently shown that the distribution of vegetation strongly links to regulating the microclimate. Consequently, these findings highlight the importance of integrating Green Infrastructure into the overall strategy for Heat Adaptation (Al-Hajri et al., 2025; Heris et al.).

Despite these established relationships, many heat mitigation guidelines still rely on broad, one-size-fits-all recommendations that overlook the unique morphological and climatic characteristics of specific neighborhoods. Scholars therefore emphasize the

need for more context-sensitive urban design and planning approaches that align mitigation strategies with local spatial configurations to maximize both heat reduction and energy efficiency (Middel et al., 2020; Marey, 2025).

2.2.3 Theories

Timothy R. Oke's (1987) Urban Microclimate Theory explains how temperature can change and climate vary within different parts of a city due to factors like urban form, materials, vegetation, and human activity. Building on this, modern tools such as AI heat mapping, IoT sensors, predictive models, and digital twins help monitor these variations in real time. it allows planners to identify hotspots, test cooling strategies, and apply targeted solutions, making Oke's theory essential to today's data-driven heat-resilience planning.

Table 2 Key Strategies for Heat Resilience and Contributions by Architects/Urban Planners

Category	Strategies for Heat Resilience	Architect / Urban Planner	Key Contribution
Nature-Based Solutions (NBS)	Urban reforestation, green roofs, tree-lined streets, wetlands, water bodies	Ken Yeang	Pioneer of bioclimatic design; advocates vertical greenery and passive cooling
Green-Blue-Grey Infrastructure	Parks, green corridors, bioswales, retention ponds, shaded pedestrian routes	Frederick Law Olmsted	Designed climate-responsive cooling public parks ("lungs of the city")
Technological Heat Mitigation	Cool roofs, reflective pavements, advanced cooling systems	Michael Reynolds	Earthship architecture; passive cooling using materials and reflective surfaces
Digital & AI-Driven Tools	AI heat mapping, IoT sensors, predictive analytics	Carlo Ratti	Uses digital sensing in cities (MIT Senseable City Lab) for microclimate analysis
Urban Planning & Design Strategies	Compact city planning, thermal zoning, transit corridors with vegetation	Jan Gehl	Human-scale urbanism integrating shaded, comfortable public spaces

2.3 The Challenge of Implementation and Intensifying Heat Stress

There are various challenges preventing the efficient rollout of ICAP measures due to persistent implementation issues within the framework, despite the framework supporting Sustainable Cooling Strategies (SCS) such as Cool Roofs, Passive Design Interventions (PDIs), and Urban Heat Island (UHI) Mitigation measures. While all of these strategies have sound conceptual bases, in practice, the rapid and unregulated nature of urbanization continues to inhibit their delivery. Therefore, as cities continue to densify, experiencing the pressures resulting from climate change and the loss of vegetation, intensified urban heat under the growing amount of built-up surfaces and reduced availability of ventilation corridors, the problem becomes a public health issue, increasing demand on existing infrastructure, and increasing demand for energy. In order to successfully deliver ICAP solutions, it is necessary to develop new strategies at a neighborhood scale that consider the variety of urban forms that exist within a neighborhood (i.e. from historical compact cores to high-density informal settlement forms). Without these additional strategies that can address the variations in urban form, the successful delivery of ICAP solutions is unlikely to be realized.

2.3.1 Influence of Urban Morphology on Heat Resilience.

A major technical barrier is the Influence of Urban Form Typologies on Heat Resilience. Different settlement patterns whether dense cores, planned colonies, or informal housing experience heat stress differently. However, current cooling efforts suffer from the Ineffectiveness of Generic Cooling Approaches. Uniform measures fail because they do not account for critical differences in density, street patterns, built form, and green cover among these typologies. This points to a significant research gap: a limited understanding of how specific Urban Form Typologies (UFTs) correlate with heat resilience and cooling strategy success in Indian cities. Without this understanding, generic interventions will continue to reduce the overall effectiveness of cooling efforts (M. Wang, Xiong, et al., 2025)

2.3.2 Need for Data-Driven, Context-Specific Strategies

To bridge these gaps, there is an explicit Need for Data-Driven and Context-Specific Cooling Strategies. Current planning often lacks the granular data necessary to make

informed decisions. This goal is to make evidence-based strategies that directly align with ICAP goals by being tailored to specific urban characteristics. The overarching research need is a used spatial-morphological assessment to guide the development of typology-based cooling interventions, ensuring that policy and practice are optimized for the unique physical and social context of each neighborhood level. (Ishak et al., 2025)

2.3.3 Evaluation of India's Heat-Resilience Policies and Missions

India has introduced several policies and missions aimed at strengthening urban heat resilience and promote climate-adaptive development. National Action Plan on Climate Change (NAPCC, 2008) supports sustainable urban habitats through cool roofs, energy-efficient building design, and enhanced urban greenery. State-level Heat Action Plans (HAPs) in Ahmedabad, Telangana, and Odisha promote early warning systems, public awareness, and targeted heat- reduction strategies under the guidance of NDMA and IMD. Urban missions such as AMRUT 2.0 and the Smart Cities Mission integrate green–blue infrastructure, reflective surfaces, and climate-sensitive mobility to address rising heat stress. The Energy Conservation Building Code (ECBC, 2017) establishes thermal comfort and insulation standards, while the National Urban Housing and Habitat Policy (2007) encourages climate-responsive and inclusive housing. Together, these frameworks create a multi-level approach to reducing urban heat stress and enhancing city-scale resilience. Still, several critical gaps remain, highlighting areas where further research is necessary.

Although strong policy frameworks, significant challenges limit effective implementation on the ground. Many national policies lack neighborhood-scale or local level guidelines, making it difficult for cities with diverse urban forms to apply cooling strategies consistently. Heat Action Plans vary widely in depth and execution, and several cities still lack detailed vulnerability mapping. Urban interventions often follow generic cooling measures without adapting to differences in density, street geometry, or green cover. Adoption of advanced technologies such as AI heat mapping, IoT sensors, and digital twins remains limited due to capacity gaps and resource constraints. Additionally, monitoring and evaluation mechanisms are weak, with few measurable indicators to assess the long-term impact of heat-resilience initiatives.

A critical shortcoming of India's present heat-resilience policies is the lack of context-specific approaches that acknowledge typology-specificity in Indian cities. Urban typologies represented in Indian cities include dense mixed-use cores, planned residential colonies, high-rise clusters, informal settlements, industrial lands, and peri-urban lands; each typology experiences distinct forms and levels of heat stress. Although heat-mitigation techniques have been developed by both the national and state governments, most of the policies are implemented using the same cool-down techniques in a "one size fits all" manner, thus failing to consider variations in density of buildings, width of streets, amount of vegetation, amount of material reflection and number of openings on each typology. Policies that recommend the installation of cool roofs, development of green infrastructure or provision of shade have created inconsistencies in heat-mitigation results between typologies. Consequently, there exists a significant disparity within heat-mitigation recommendations and what is actually occurring spatially and morphologically within Indian cities. Accordingly, in order to develop effective heat-mitigation solutions, it is critical to establish typology-based cooling strategies that are based on data collected from the particular types of urban areas in which they will be applied.

2.4 Gaps

India's efforts to address rising urban heat include several national and state-level initiatives, yet multiple challenges persist across planning and implementation scales. Although the India Cooling Action Plan (2019) promotes passive design, cool roofs, and urban heat island reduction, its on-ground application remains limited due to the absence of neighborhood-specific strategies. Rapid and often unplanned urban growth has intensified heat waves and UHI effects, stressing public health and infrastructure; however, existing Heat Action Plans provide only partial insights into the spatial factors that shape vulnerability at the local scale. Variations in settlement patterns like as dense traditional cores, planned colonies, informal settlements, and expanding peripheral areas create distinct heat exposures, but research linking these urban form typologies to heat resilience remains underdeveloped. Current cooling interventions tend to be uniform, overlooking differences in density, vegetation, street configuration, and built morphology, which reduces their effectiveness in diverse urban settings. Although national frameworks like ECBC, NAPCC, NDMA guidelines, and smart city platforms

support energy efficiency and adaptive planning, there is still a need for detailed spatial–morphological assessments to guide evidence-based, typology-specific, and context-responsive cooling solutions across Indian cities.

1. National cooling policies promote passive design and UHI reduction, but cities still lack clear, neighborhood-level strategies or methods for practical implementation.
2. Rapid urbanization has intensified heat stress, and although Heat Action Plans exist, they do not fully address how local spatial patterns shape vulnerability.
3. Different urban form typologies experience heat differently, still limited research links these forms to effective cooling solutions.
4. Generic cooling measures overlook variations in density, vegetation, and street layout, reducing their effectiveness in real urban conditions.
5. Supportive national frameworks, cities still need data-driven, morphology- based strategies to design context-specific cooling interventions for this specific.

Table 3 Identification of research gaps.

No.	Key Issue	Description of the Problem	Existing Efforts / Policies	Research Gap / Need
1	Implementation Challenges in ICAP (India Cooling Action Plan)	Promotes sustainable cooling, passive design, cool roofs, and UHI reduction.	India Cooling Action Plan (2019)	Lack of practical neighbourhood-scale implementation strategies for diverse urban forms.
2	Intensifying Urban Heat Stress	Rapid urbanization and unplanned growth have intensified heat waves and UHI effects, increasing risks to health, energy use, and infrastructure.	State-level Heat Action Plans (HAPs)	Limited understanding of spatial factors contributing to neighbourhood-level heat vulnerability.

3	Influence of Urban Form Typologies on Heat Resilience	Different settlement types (dense cores, planned colonies, informal settlements, peripheries) experience varying heat levels.	Smart Cities Mission, AMRUT 2.0	Limited research linking urban form typologies (UFTs) to heat resilience and effective cooling strategies.
4	Ineffectiveness of Generic Cooling Approaches	Current cooling measures are uniform and ignore variations in density, vegetation, street layout, and built form.	ECBC (2017), NAPCC	Lack of typology-specific cooling approaches, reducing intervention effectiveness.
5	Need for Data-Driven and Context-Specific Cooling Strategies	Cooling strategies require evidence-based alignment with urban morphology.	NDMA, IMD, Smart City data platforms	Lack of spatial–morphological assessment to guide data-driven and typology-based cooling solutions.

Indore, located at 22.72° N latitude and 75.86° E longitude on the Malwa Plateau in central India, lies at an average elevation of about 553 meters above sea level**.** The city experiences a humid subtropical climate**,** with extremely hot summers where temperatures can reach up to 45°C**,** moderate monsoon rainfall ranging between, and relatively mild winters. According to the **2011 Census**, Indore has a population of approximately **1.99 million**, with an urban agglomeration of around 2.17 million**,** while the current metropolitan population is estimated to exceed 3 million. In recent decades, Indore has and human thermal comfort. At the neighborhood scale, urban areas function as microclimatic units where factors such as building density, street orientation, vegetation distribution, and surface materials significantly determine heat exposure and thermal conditions. (Emmanuel and Krüger 2012). These localized characteristics play a critical role in either intensifying or mitigating heat stress.

Assessing heat resilience at this scale enables the identification of vulnerable zones and supports the formulation of targeted mitigation strategies. Such strategies include urban greening, cool roofing, enhanced ventilation, and climate-sensitive planning approaches aimed at improving overall urban livability. (Bowler et al. 2010; Santamouris 2015). Understanding of spatial heat patterns and supports evidence-based planning interventions. (Weng et al. 2004).

Chapter-3

Study Area and City Profile

Indore is the largest city in the state of Madhya Pradesh, India, and serves as its commercial capital. Located on the Malwa Plateau, the city has experienced rapid urbanization and economic growth over the past few decades. Indore is known for its strong industrial base, educational institutions, and well-developed infrastructure. It has consistently been ranked among the cleanest cities in India under the Swachh Survekshan survey. Due to increasing urban expansion, changes in land use, and rising temperatures, Indore has become an important case study for urban climate, heat risk, and sustainable urban planning research.

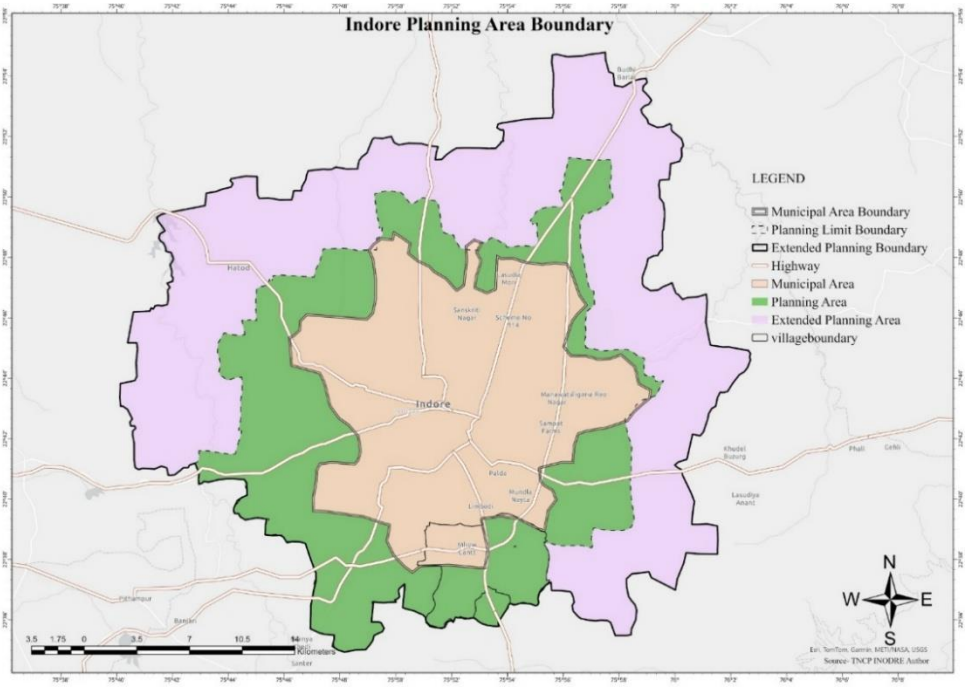


Figure 6. Indore planning Area Boundary *Source :- Author, IDA*

The map i.e. Figure 6 illustrates the spatial extent of the **Indore Planning Area**, showing the municipal boundary, planning limit boundary, and extended planning area. The municipal area forms the urban core of Indore city, while the surrounding planning and extended planning areas represent zones identified for future urban growth and development. Major highways and village boundaries are also depicted, highlighting the regional connectivity and administrative structure of the planning region.

The planning area covers both developed urban zones and peripheral rural settlements, indicating the expansion of urban influence beyond the municipal limits. Such spatial

delineation is important for urban planning, infrastructure provision, land-use regulation, and sustainable regional development in Indore.

Indore, the commercial capital of Madhya Pradesh, is one of the fastest-growing urban centers in central India. Located on the Malwa Plateau at an elevation of approximately 553 m above sea level, the city has experienced significant population growth, urban expansion, and infrastructure development over the past two decades. These rapid urbanization processes have transformed natural and open spaces into built-up areas, influencing the city's thermal environment and increasing susceptibility to urban heat stress.

The continuous increase in built-up areas, reduction of open and vegetated spaces, and expansion of impervious surfaces have contributed to rising land surface temperatures (LST) and the formation of urban heat hotspots. These changes make Indore an ideal case study for analysing the relationship between urban form and thermal characteristics. The presence of diverse Local Climate Zones (LCZs), varying building densities, and different surface materials provides an excellent opportunity to examine how urban morphology influences heat distribution across the city. Therefore, Indore has been selected as the study area to assess urban heat patterns and develop planning strategies for improving thermal comfort and enhancing urban climate resilience.

The city experiences a tropical savanna climate (Aw) characterized by hot summers, a monsoon season, and mild winters. Summer temperatures often range between 40°C and 45°C, while annual rainfall averages around 1000 mm, most of which occurs between June and September. Prolonged periods of high temperatures, combined with dense urban development, contribute to elevated land surface temperatures and the formation of urban heat hotspots across the city.

city's strategic location and well-developed transportation network have further accelerated urbanization, resulting in significant changes in land use and land cover.

Indore was selected as the study area due to its diverse urban morphology, ranging from compact commercial districts and dense residential neighbourhoods to industrial zones and peri-urban areas. This diversity provides an excellent opportunity to examine the relationship between urban form typologies and heat risk. Furthermore, the availability of satellite imagery, geospatial datasets, and Local Climate Zone (LCZ) classifications enables detailed assessment of Land Surface Temperature (LST) variations and urban heat patterns.

The study considers the Indore Planning Area as the spatial boundary for analysis. The planning area encompasses existing municipal limits as well as surrounding urban expansion zones governed by planning regulations.

The study area contains a wide range of Local Climate Zones (LCZs), making it suitable for evaluating the influence of different urban forms on Land Surface Temperature. The planning area boundary forms the basis for all GIS analyses, hotspot identification, and urban heat assessments conducted in this research.

urban structure of Indore consists of a mixture of residential, commercial, institutional, industrial, and recreational land uses. The central part of the city is characterized by dense built-up development, whereas newly developed peripheral areas consist mainly of residential townships and industrial zones.

Major transportation corridors, commercial hubs, and industrial estates contribute to high surface temperatures because of extensive paved surfaces and limited vegetation. In contrast, parks, water bodies, and open green spaces help reduce local temperatures by providing cooling effects.

- Largest and fastest-growing city in Madhya Pradesh.
- Located in a hot tropical savanna climate with summer temperatures exceeding **40°C**.
- Rapid urbanization and expansion of built-up areas have altered the urban microclimate.
- Increasing occurrence of urban heat stress and heat-risk hotspots.

- Presence of diverse **Local Climate Zones (LCZs)** and urban form typologies.
- Availability of reliable satellite and GIS data for spatial analysis.
- Suitable for evaluating the influence of BSF, PSF, ISF, and SVF on Land Surface Temperature.
- Provides a representative case for developing heat-resilient urban planning and design strategies for

Chapter-4
Data Formulation & Analysis

The map illustrates the spatial distribution of Local Climate Zones (LCZs) within the Indore Planning Area using the WUDAPT classification framework. It shows that compact urban zones (LCZ 1–3) are concentrated in the city center, while open and sparsely built zones dominate the peripheral areas. Vegetation classes, including dense trees and low plants, are mainly distributed along the urban fringe. This LCZ classification provides a foundation for analyzing urban form characteristics and their influence on heat risk patterns across Indore.

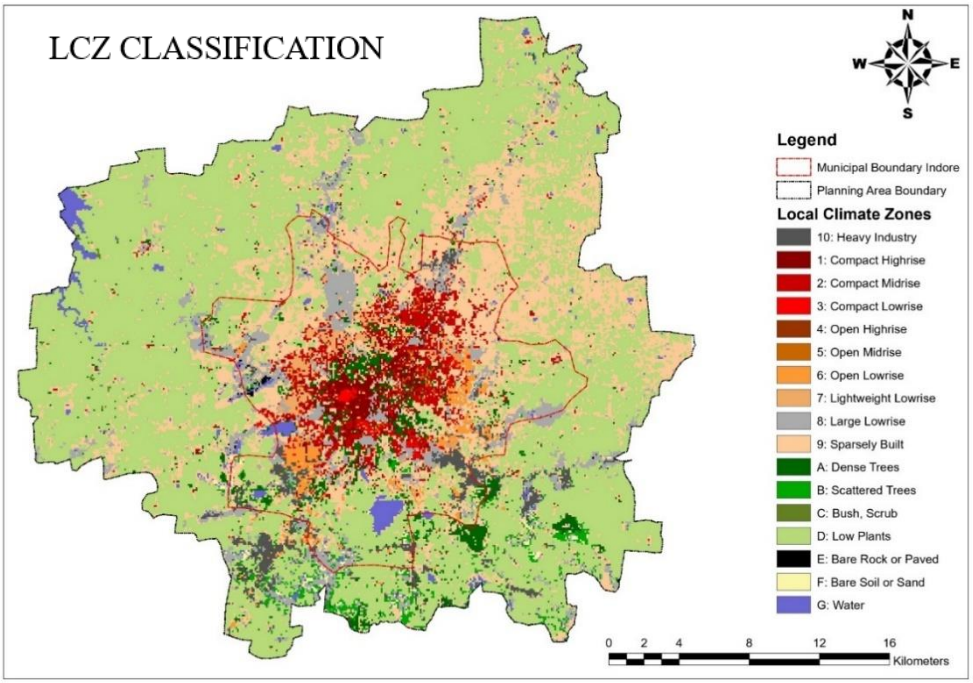


Figure 7. LCZ Local Climate Zone Classification Map of Indore Planning Area *Source :- Author*

- The map i.e. Figure 7 presents the spatial distribution of **Local Climate Zones (LCZs)** within the Indore Planning Area, illustrating the variation in urban morphology, land cover, and built-up characteristics across the city. The central urban core is predominantly occupied by compact low-rise, compact mid-rise, and open low-rise development, representing densely built urban neighbourhoods with high impervious surface concentration. Industrial zones are identified in specific pockets, while sparsely built and lightweight low-rise areas are mainly observed toward the urban periphery.

- Natural land cover classes such as dense trees, scattered trees, low plants, bare soil, and water bodies are distributed around the outer planning region and along open spaces within the city. The LCZ classification highlights the contrast between highly urbanized zones and vegetated areas, which is important for understanding urban heat patterns, thermal behaviour, and environmental conditions. This spatial classification provides a strong basis for analysing land surface temperature, heat vulnerability, and climate-responsive urban planning strategies in Indore.

- This classification helps in understanding urban heat patterns, thermal variation, and the relationship between built-up areas and environmental conditions within the planning area.

- This study uses a geospatial approach integrating Land Surface Temperature (LST), NDVI, built-up density.

1. Heat resilience is the ability of urban areas to withstand, adapt to, and recover from extreme heat conditions such as heatwaves and the Urban Heat Island effect (Oke 1982; Santamouris 2015).

2. It is influenced by urban form, land use, green cover, building materials, and socio-economic conditions, which together shape local temperature variations and thermal comfort (Stewart and Oke 2012).

3. Urban neighbourhoods act as microclimatic units where building density, street orientation, vegetation, and surface materials determine heat exposure levels (Emmanuel and Krüger 2012).

4. High built density and low vegetation often increase heat stress, while green infrastructure helps reduce temperatures and improve comfort (Bowler et al. 2010).

5. Assessment helps identify heat-vulnerable zones and supports targeted planning interventions.

6. Key mitigation strategies include urban greening, cool roofs, improved ventilation, and climate-sensitive urban design (Santamouris 2015).

4.1 Data Collection

Satellite Data Acquisition:

Multispectral imagery from Landsat 8 was obtained through platforms such as USGS Earth Explorer. Cloud-free images for the years **2015 and 2025** were selected to ensure accuracy in analysis.

Image Selection Criteria:

1. Minimal cloud cover (<10%)
2. Same seasonal period (preferably summer) for consistency in temperature comparison
3. Adequate spatial resolution (30 m) for urban-scale analysis

Pre-processing of Data:

1. Radiometric and atmospheric correction of satellite images
2. Layer stacking and band selection for analysis
3. Clipping of imagery using the city boundary shapefile

Extraction of Indices:

1. **NDVI** derived from red and near-infrared bands to assess vegetation cover
2. **NDBI** calculated using shortwave infrared and near-infrared bands to map built-up areas
3. **LST** extracted from thermal infrared bands to analyze surface temperature distribution

Ancillary Data Collection:

Administrative boundary (shapefile) collected from municipal or planning authority sources to define the study area

Data Integration:

All datasets were processed and analyzed within a GIS environment (e.g., ArcGIS) to ensure spatial consistency and enable overlay analysis

4.2 Data Sources

Satellite Data:

Multispectral satellite imagery from Landsat 8 is used as the primary data source. It provides moderate-resolution imagery suitable for analyzing urban environmental conditions.

Temporal Coverage:

The study utilizes data from two time periods, **2015 and 2025**, to assess temporal changes in urban heat patterns and land cover dynamics.

Derived Datasets:

1. **NDVI (Normalized Difference Vegetation Index):** Used to assess vegetation cover and green infrastructure distribution across the study area.
2. **LST (Land Surface Temperature):** Extracted to analyze spatial variations in surface temperature and identify urban heat hotspots.
3. **NDBI (Normalized Difference Built-up Index):** Applied to map built-up areas and understand the extent of urbanization.

Ancillary Data:

City Boundary (Shapefile): Administrative boundary data is used to define the study area and to clip and standardize all spatial datasets for consistent analysis.

4.3 NDVI (Data Analysis)

FORMULA:- NDVI=NIR-Red/NIR+Red

The Normalized Difference Vegetation Index (NDVI) is a widely used remote sensing indicator for assessing vegetation health and density. It is derived from satellite imagery using the reflectance values of the near-infrared (NIR) and red bands. NDVI values range from -1 to +1, where higher values indicate dense and healthy vegetation, while lower values represent sparse vegetation, bare land, or built-up areas. In urban heat

studies, NDVI is commonly used to evaluate the influence of vegetation cover on surface temperature and heat risk.

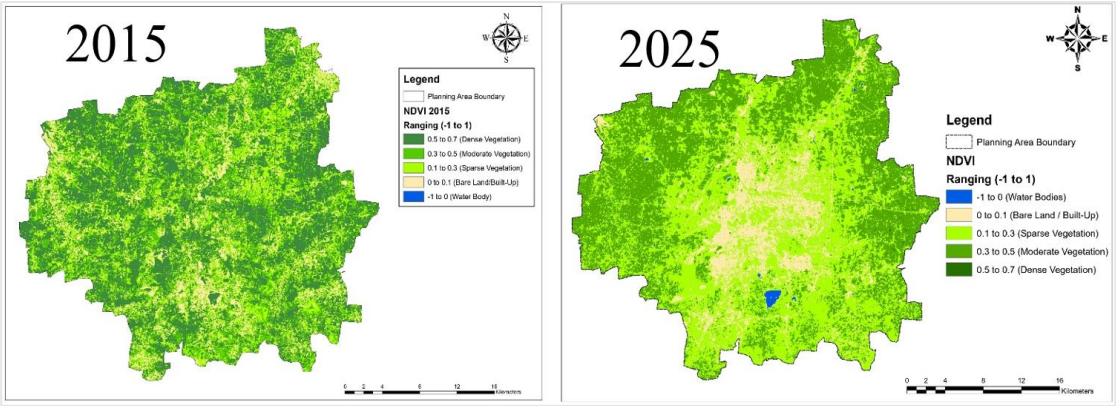


Figure 8 NDVI Landsat 8 satellite imagery *Source :- Author*

NDVI Analysis

Normalized Difference Vegetation Index (NDVI) as seen in Figure 8 is used to measure the presence and health of vegetation using satellite imagery. The formula compares the reflectance values of the Near-Infrared (NIR) and Red bands. Healthy vegetation reflects more NIR radiation and absorbs more red light, resulting in higher NDVI values.

Formula: $NDVI = \frac{NIR-Red}{NIR+Red}$

In the study area, higher NDVI values indicate dense vegetation cover such as parks, trees, and agricultural land, whereas lower NDVI values represent built-up areas, barren land, or impervious surfaces. Areas with high NDVI generally show lower land surface temperatures due to the cooling effect of vegetation, while low NDVI zones are associated with higher thermal intensity and urban heat island effects.

2015 MAP

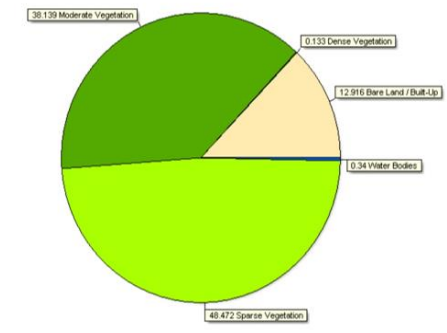
The NDVI analysis for 2015 i.e. Figure 8 indicates a clear spatial variation in vegetation distribution across the study area. Areas with dense vegetation are predominantly located in the peripheral zones, reflecting the presence of open land, agricultural areas,

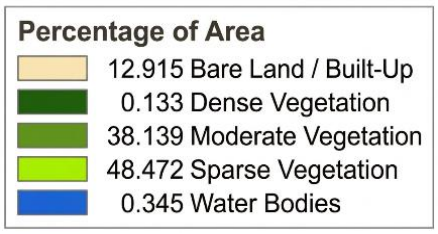
or less urbanized regions. In contrast, moderate vegetation is dispersed throughout the city, suggesting fragmented green cover within residential and mixed-use areas.

The central urban core is characterized by sparse vegetation, highlighting limited green spaces and a higher degree of built-up development. This is further supported by the concentration of built-up and bare land surfaces in these core areas, which contributes to reduced vegetation density. Additionally, the presence of water bodies is minimal**,** indicating limited natural cooling elements within the urban fabric.

2025 MAP

NDVI analysis as mentioned in Figure 8 indicates a noticeable transformation in vegetation patterns, with dense vegetation in peripheral areas becoming reduced and fragmented**,** reflecting increasing land conversion and urban expansion. While moderate vegetation is still present across the city, its extent has slightly decreased, suggesting a gradual loss of green cover. At the same time, sparse vegetation has increased in the central and mid-urban areas**,** highlighting intensifying urbanization and pressure on existing green spaces. This is further reinforced by the significant expansion of built-up and bare land in the urban core**,** indicating higher development density. Additionally, water bodies remain limited with only minor spatial **distribution**, reducing their potential role in urban cooling. Overall, the pattern reflects a shift towards a more built-dominated landscape with declining vegetation cover.





Analysis: -

Central area has low NDVI + high heat

Planning Implication:

Increase tree plantation in core areas

1. Introduce shaded streets

2. Reduce heat through cool materials.

4.4 NDBI (Built-up Analysis)

The Normalized Difference Built-up Index (NDBI) is a remote sensing index used to identify and map built-up or urbanized areas from satellite imagery. It is calculated using the reflectance values of the Short-Wave Infrared (SWIR) and Near-Infrared (NIR) bands. NDBI values typically range from -1 to +1, where higher values indicate built-up surfaces such as buildings, roads, and other impervious areas, while lower values represent vegetation and water bodies. In urban heat studies, NDBI is widely used to assess the relationship between urban development and increased land surface temperatures.

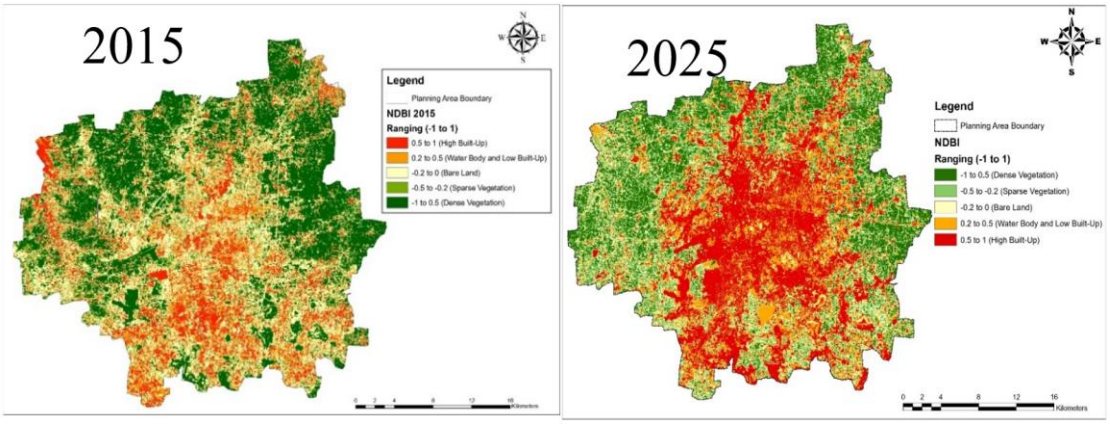


Figure 9 NDBI Landsat 8 satellite imagery *Source :- Author*

The NDBI map for 2015 shows that built-up areas are moderately concentrated in the central region**,** while vegetation dominates the peripheral zones, indicating a less urbanized edge. Urban growth appears scattered and relatively low in density, with the presence of mixed land-use zones highlighting transitional areas between built-up and

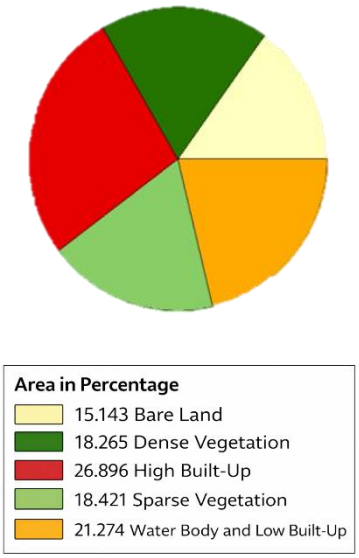
green spaces. Overall, the city reflects an early stage of urban expansion**,** where the urban core exists but is not highly compact**,** and the outskirts remain largely eco-dominant with dense vegetation.

The built-up index is calculated using the Normalized Difference Built-up Index formula:

Formula :-
NDBI=Band 6 (SWIR)+Band 5 (NIR)/Band 6 (SWIR)−Band 5 (NIR)

The NDBI analysis for 2025 reveals a significant increase in high built-up areas across the city**,** with the urban core becoming highly dense and compact**.** There is a clear expansion of built-up zones toward the outskirts**,** accompanied by a noticeable reduction in dense vegetation**.** The rise in low built-up and mixed-use areas further indicates ongoing urban sprawl. Overall, this pattern reflects rapid urbanization and infrastructural growth**,** where green and open lands are being transformed into built-up areas, resulting in both intensification in the core and spatial expansion at the periphery**.**

Forms a continuous heat-prone urban core. This area has maximum heat absorption, low cooling capacity, and poor thermal comfort. Transition Zone Mixed built-up and vegetation areas Broken and scattered green patches Some cooling is present, but not effective due to fragmentation



4.5 Land Surface Temperature Analysis

Land Surface Temperature (LST) refers to the temperature of the Earth's surface as measured from satellite thermal infrared data. It represents the heat emitted by natural and built-up surfaces such as vegetation, soil, roads, and buildings. LST is an important indicator for analyzing urban heat patterns and identifying heat-prone areas. Higher LST values are generally associated with dense built-up areas and impervious surfaces, while lower values are observed in vegetated and water-covered regions. In urban climate studies, LST is widely used to assess heat risk and the Urban Heat Island (UHI) effect.

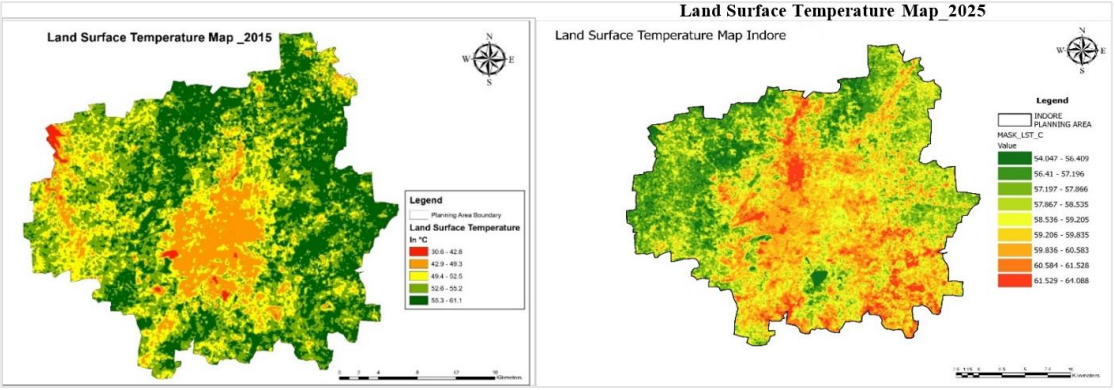


Figure 10 NDBI Landsat 8 satellite imagery *Source :- Author*

LST Map Analysis – 2015

The LST analysis for 2015 shows that the central region experiences moderate to high temperatures**,** represented by orange to red zones, while the peripheral areas remain relatively cooler**,** dominated by green zones. The overall temperature distribution appears balanced, exhibiting a clear urban–rural gradient. The presence of green patches corresponds to areas with dense vegetation, contributing to lower surface temperatures.

LST Map Analysis – 2025

The LST analysis for 2025 indicates a significant increase in high-temperature zones across the city**,** with heat intensity expanding from the central core toward the peripheral areas. There is a clear reduction in cooler zones, along with the formation of continuous

heat clusters**,** particularly in densely built-up regions. This pattern reflects a strong **Urban Heat Island effect,** driven by rapid urban growth, loss of vegetation, and increased built-up surfaces. As a result, heat is now more widespread and less localized**,** indicating a decline in overall urban thermal comfort.

1. ML, AL: Radiance rescaling factors (from metadata)
2. Qcal: Digital number (pixel value)
3. K1, K2: Thermal conversion constants
4. λ (Lambda): Wavelength of emitted radiance
5. ε (Emissivity): Depends on surface (vegetation, soil, etc.)

4.6 – Spatial Analysis of Land Surface Temperature: Core Hotspot Identification

The analysis of Local Climate Zones (LCZ) in Indore reveals a strong correlation between urban form and the spatial distribution of heat hotspots. A high concentration of hotspots is observed in Compact Low-rise (LCZ 3) and Compact Midrise (LCZ 2) areas, indicating dense built-up environments characterized by limited ventilation and high heat retention capacity. Similarly, Compact Highrise (LCZ 1) zones, primarily located in the Central Business District (CB D) and core city areas, exhibit significant clustering of hotspots due to high building density and reduced sky view factor, which restricts heat dissipation. In contrast, Open Midrise (LCZ 5) and Open Highrise (LCZ 4) zones display comparatively fewer hotspots, suggesting improved airflow and lower heat accumulation resulting from more open urban layouts. Additionally, Heavy Industrial (LCZ 10) areas show distinct hotspot clusters, primarily driven by anthropogenic heat emissions and industrial activities. Peripheral and low-density areas demonstrate minimal hotspot presence, further confirming a strong relationship between increasing urban density and rising heat intensity within the city.



Figure 11. Spatial Analysis _Core Hotspot Area *Source:- Author*

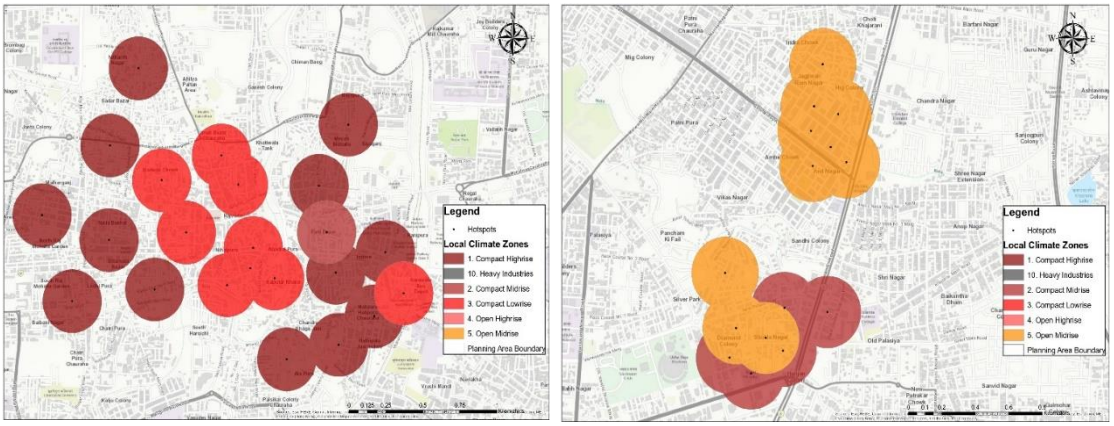


Figure 12. Spatial Analysis _Core Hotspot Area Correlation *Source:- Author*

The analysis of Local Climate Zones (LCZ) in Indore reveals a strong correlation between urban form and the spatial distribution of heat hotspots. A high concentration of hotspots is observed in Compact Low-rise (LCZ 3) and Compact Midrise (LCZ 2) areas, indicating dense built-up environments characterized by limited ventilation and high heat retention capacity. Similarly, Compact Highrise (LCZ 1) zones, primarily located in the Central Business District (CB D) and core city areas, exhibit significant clustering of hotspots due to high building density and reduced sky view factor, which restricts heat dissipation. In contrast, Open Midrise (LCZ 5) and Open Highrise (LCZ 4) zones display comparatively fewer hotspots, suggesting improved airflow and lower heat accumulation resulting from more open urban layouts. Additionally, Heavy Industrial (LCZ 10) areas show distinct hotspot clusters, primarily driven by anthropogenic heat emissions and industrial activities. Peripheral and low-density areas demonstrate minimal hotspot presence, further confirming a strong relationship between increasing urban density and rising heat intensity within the city.

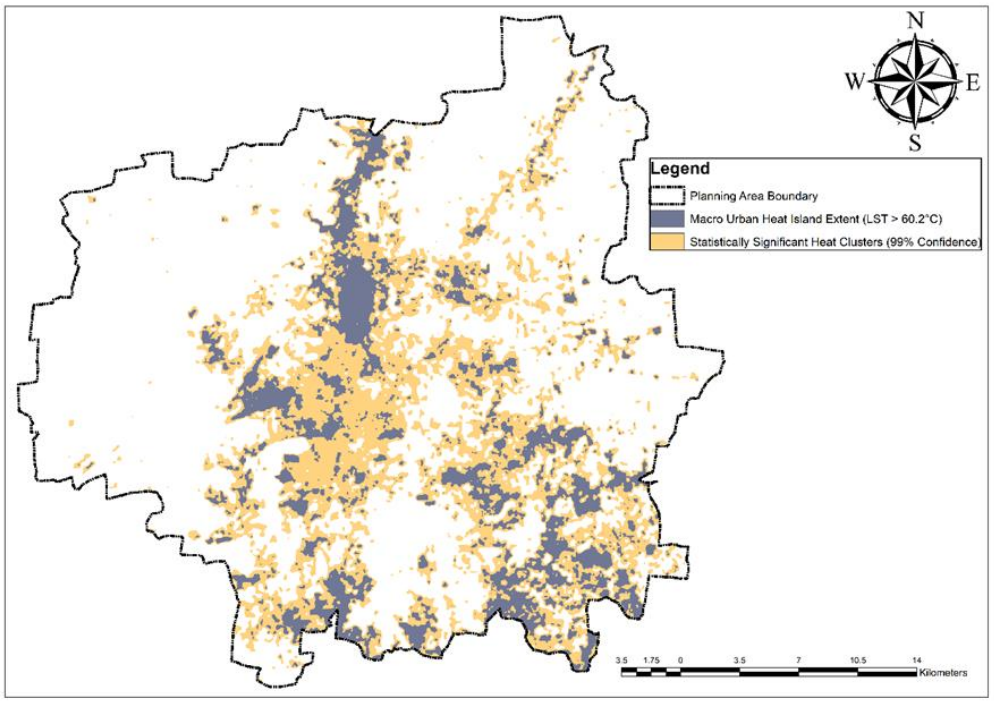


Figure 13 Mapping of Significant Hotspot Zones *Source:-Author*

4.7 – Spatial Analysis of Statically Significant Heat Cluster:

It shows clustered high values (e.g., high temperature areas).

Using $p < 0.01$(There is less than 1% chance that the observed pattern This hotspot is very strong and not random.

1. The results indicate positive spatial autocorrelation of high LST values, meaning hot areas are surrounded by hot areas.

2. The use of 99% confidence level ($p < 0.01$) ensures high reliability and robustness of hotspot detection.

3. The dominance of hotspots over cold spots suggests a skewed thermal distribution toward higher temperatures.

4. This confirms that the Urban Heat Island effect is statistically significant and spatially concentrated, rather than incidental.

This map represents the spatial distribution of Urban Heat Island (UHI) intensity within the planning boundary, highlighting both macro-level heat extent (LST > 60.2°C) and statistically significant heat clusters (99% confidence level). The pattern shows that

high-temperature zones are not uniformly distributed but are concentrated in dense and built-up areas, particularly in the central, southern, and south-eastern parts of the city. These grey-coloured macro UHI patches indicate areas experiencing extreme surface temperatures, likely due to high building density, impervious surfaces, and limited vegetation cover.

The yellow clusters are more widespread and indicate statistically significant pockets of heat concentration, even beyond the extreme UHI zones. This suggests that while some areas may not exceed the 60.2°C threshold, they still exhibit consistent spatial clustering of high temperatures, making them thermally vulnerable. The overlap between grey and yellow areas highlights critical heat-risk zones, where both intensity and statistical significance are high.

Peripheral areas, especially towards the outer north and west, show relatively fewer hotspots, indicating lower urbanization or higher vegetation presence, which helps in temperature regulation. The fragmented pattern of hotspots also suggests heterogeneous urban morphology, where land use, built form, and green cover vary significantly across the city.

The hotspot analysis map highlights the spatial distribution of statistically significant heat clusters within the Indore Planning Area. Red-colored zones represent hotspots, indicating areas with consistently high land surface temperatures, while blue-colored zones represent cold spots with relatively lower temperatures. The map shows that major heat hotspots are concentrated in the central and southern urbanized regions, whereas cold spots are mainly located in the peripheral areas with higher vegetation cover and open spaces. This pattern reflects the influence of urban development and land cover on heat distribution across the city.

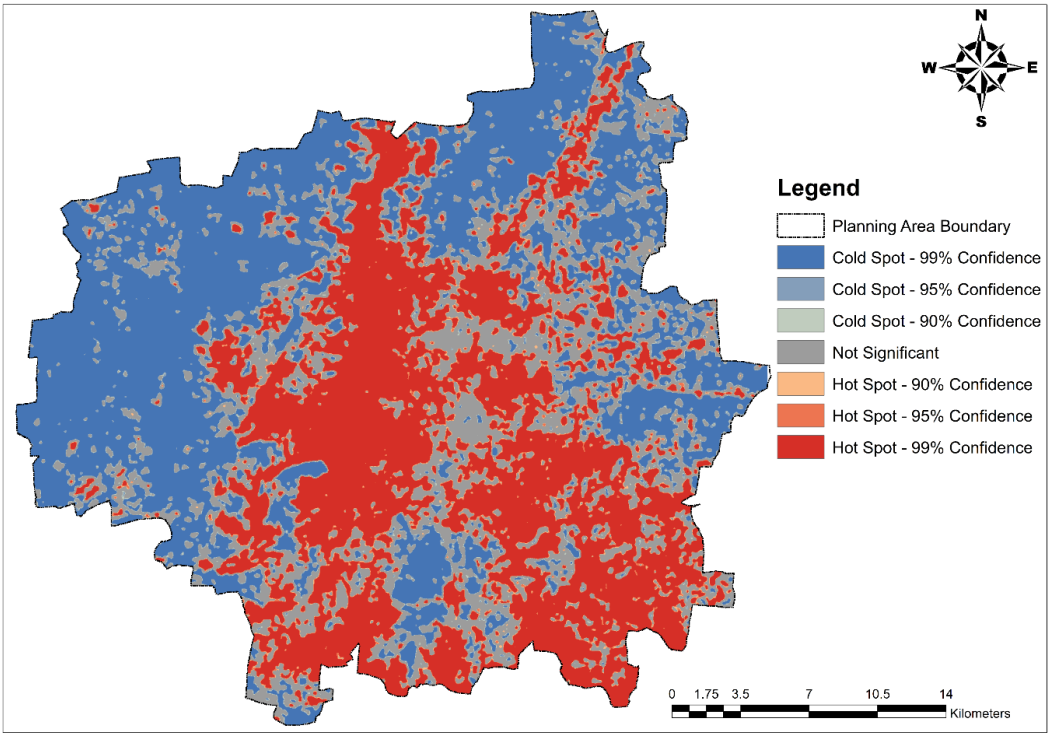


Figure 14 Hotspot areas and Cold spot Areas *Source:-Author*

4.8 Spatial Interpretation of Getis-Ord Gi* Hotspot and Cold Spot Analysis

The Getis-Ord Gi* hotspot analysis map represents the spatial distribution of statistically significant hot and cold spots within the planning area. The red-coloured regions indicate hot spots, representing areas with significantly high clustered values at different confidence levels (90%, 95%, and 99%), while the blue-coloured regions represent cold spots, indicating clusters of significantly low values. Grey areas are statistically not significant, showing no strong spatial clustering pattern.

The map clearly shows that the southern, south-eastern, and central parts of the planning area are dominated by hot spots, particularly at the 99% confidence level. This indicates a strong concentration of high-intensity values in these regions, which may correspond to densely built-up urban areas, impervious surfaces, high land surface temperature (LST), or reduced vegetation cover. The continuous clustering pattern suggests intense urbanization and compact development, leading to increased thermal accumulation and urban heat island effects.

In contrast, the northern, north-western, and western portions of the planning area are predominantly characterized by cold spots, especially at the 99% confidence level. These regions represent lower clustered values and may correspond to areas with greater vegetation cover, open spaces, agricultural land, water bodies, or lower built-up density. The presence of extensive cold spot clusters indicates relatively cooler environmental conditions and better ecological balance compared to the hotspot regions.

The scattered grey patches across the study area represent locations where the spatial pattern is not statistically significant. These areas indicate transitional zones where neither high nor low clustering is dominant.

The concentration of hotspots in the central and southern parts suggests the influence of dense urban morphology and limited green infrastructure, whereas the cold spots highlight environmentally stable zones with lower thermal stress. This spatial pattern can support urban planners in identifying priority areas for heat mitigation strategies, green infrastructure development, and sustainable land-use planning.

The Getis-Ord Gi* statistical analysis was employed to examine the spatial autocorrelation and clustering pattern within the planning area by identifying statistically significant hot and cold spot zones at 90%, 95%, and 99% confidence intervals. The resulting spatial distribution highlights the presence of strong positive spatial dependence, where similar high or low values are geographically concentrated rather than randomly distributed. In the map, red tonal variations represent hotspot clusters corresponding to significantly high values, whereas blue tonal variations indicate cold spot clusters associated with significantly low values. Grey areas represent statistically insignificant regions where clustering patterns are weak or spatially random.

The spatial configuration of hotspots demonstrates a pronounced concentration across the central, southern, and south-eastern sectors of the planning area, with the majority of these regions classified under the 99% confidence level. The persistence of highly significant hotspot clusters suggests the existence of intense spatial aggregation of elevated values, which may be strongly influenced by dense urban morphology, compact built-up structures, extensive impervious surfaces, anthropogenic heat release,

and limited vegetation cover. Such spatial continuity of hotspots indicates areas experiencing elevated thermal accumulation and intensified Urban Heat Island (UHI) conditions. The clustering pattern further reflects the impact of rapid urban expansion and unregulated land transformation processes that modify the local microclimatic regime.

The central urban core appears to function as a dominant thermal nucleus, from which hotspot intensity extends radially towards the southern and eastern corridors. This spatial trend may correspond with transportation corridors, commercial zones, industrial activities, and high-density residential developments, all of which contribute to increased surface heat retention and reduced evapotranspiration capacity. The fragmentation of hotspot patches in peripheral transitional zones indicates varying degrees of urban intensity and heterogeneous land-use characteristics.

In contrast, the northern, north-western, and western regions are predominantly characterized by statistically significant cold spot clusters, particularly under the 95% and 99% confidence intervals. These cold spots represent areas of relatively lower clustered values and are likely associated with environmentally stable landscapes such as vegetation-rich zones, agricultural land, open spaces, peri-urban regions, and water-influenced surfaces. The extensive distribution of cold spot zones suggests the presence of favourable surface permeability, higher moisture retention, and enhanced cooling effects resulting from vegetation-induced evapotranspiration. These areas exhibit comparatively lower thermal stress and serve as ecological buffers against excessive urban heating.

The scattered non-significant zones distributed between hotspot and cold spot regions indicate transitional landscapes where spatial association is relatively weak. These areas may represent mixed land-use patterns or regions undergoing gradual urban transformation, where neither high-value nor low-value clustering dominates the spatial structure. Such transitional zones often signify dynamic urban interfaces susceptible to future thermal alteration under continued urban growth.

Satellite Data → LST Extraction → Raster Clipping → Raster to Point → Getis-Ord Gi* Analysis → Hot Spot & Cold Spot Mapping

4.9 Spatial Analysis of Land Surface Temperature: Core Hotspot Identification

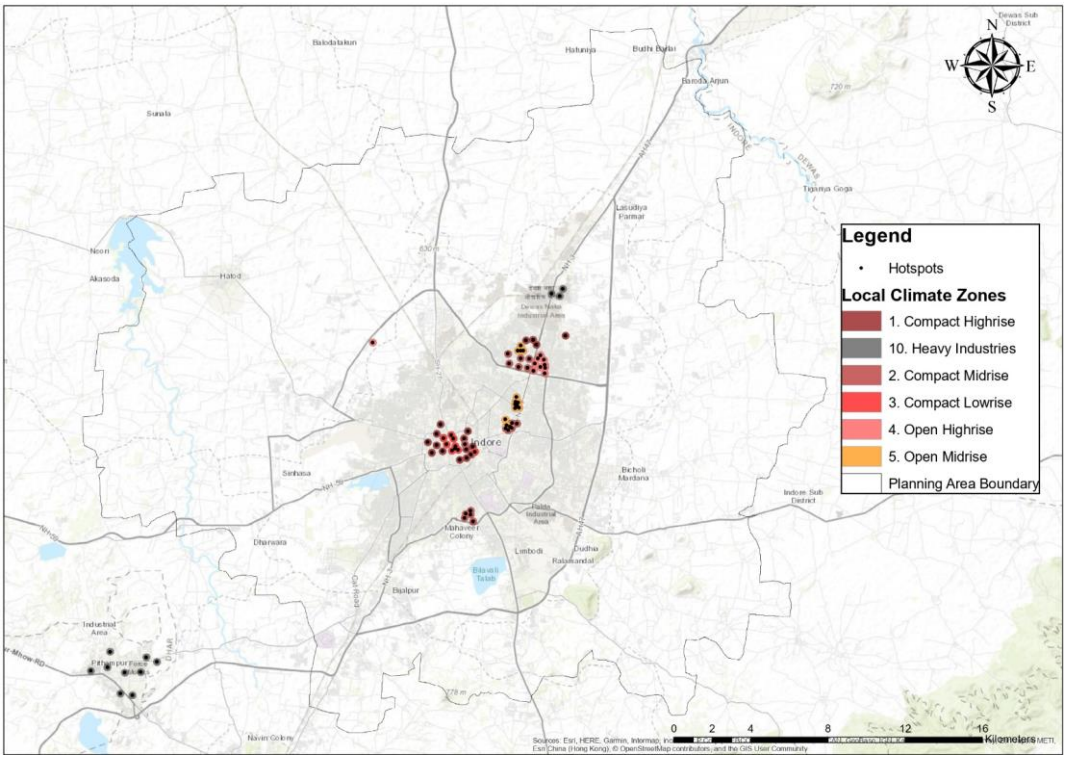


Figure 15 LCZ-based hotspot analysis of Indore *Source :- Author*

The LCZ-based hotspot analysis of Indore reveals that the highest concentration of urban heat hotspots is primarily observed in Compact Low-rise (LCZ 3) and Compact Midrise (LCZ 2) zones. These areas represent densely built-up urban environments characterized by limited open spaces, poor ventilation, and high heat retention capacity, which significantly contribute to elevated land surface temperatures. Compact Highrise (LCZ 1) **See Figure 12** zones, mainly concentrated within the Central Business District (CBD) and core city areas, also exhibit notable clustering of hotspots due to high building density and reduced Sky View Factor (SVF), restricting natural cooling and airflow. In contrast, Open Midrise (LCZ 5) and Open Highrise (LCZ 4) zones demonstrate comparatively fewer hotspots, indicating improved air circulation, greater openness, and lower heat accumulation. Additionally, Heavy Industrial (LCZ 10) areas display distinct hotspot clusters, primarily resulting from anthropogenic heat emissions and intensive industrial activities. On the other hand, peripheral and low-density urban areas show minimal hotspot presence, thereby confirming a strong relationship between urban density, built-up intensity, and urban heat concentration within the study area.

4.9.1 Identification of Core Heat Hotspots Using LCZ Analysis

The selected sites include high-rise residential, commercial, institutional, and open spaces located within the Central Business District (CBD) of Indore. These locations represent different Local Climate Zones (LCZs), reflecting variations in urban form, building density, land cover, and thermal characteristics across the study area.

Study locations were selected from the Central Business District (CBD) of Indore covering diverse urban environments.



Figure 16 LCZ Based Analysis *Source :-Author*

1. Building height & density variation
2. Mixed land use (residential, commercial)
3. High impervious surfaces (built-up areas)
4. Low pervious surfaces & vegetation (NDVI)
5. High built-up intensity (NDBI)
6. Variation in land surface temperature (LST)

7. High-rise areas: dense & low ventilation

8. Open areas: lower heat accumulation

9. Commercial zones: highly impervious

10. Overall low greenery → heat build-up

4.9.2 Identification of Core Heat Hotspots areas (LCZ1, 2, 3 & 4)

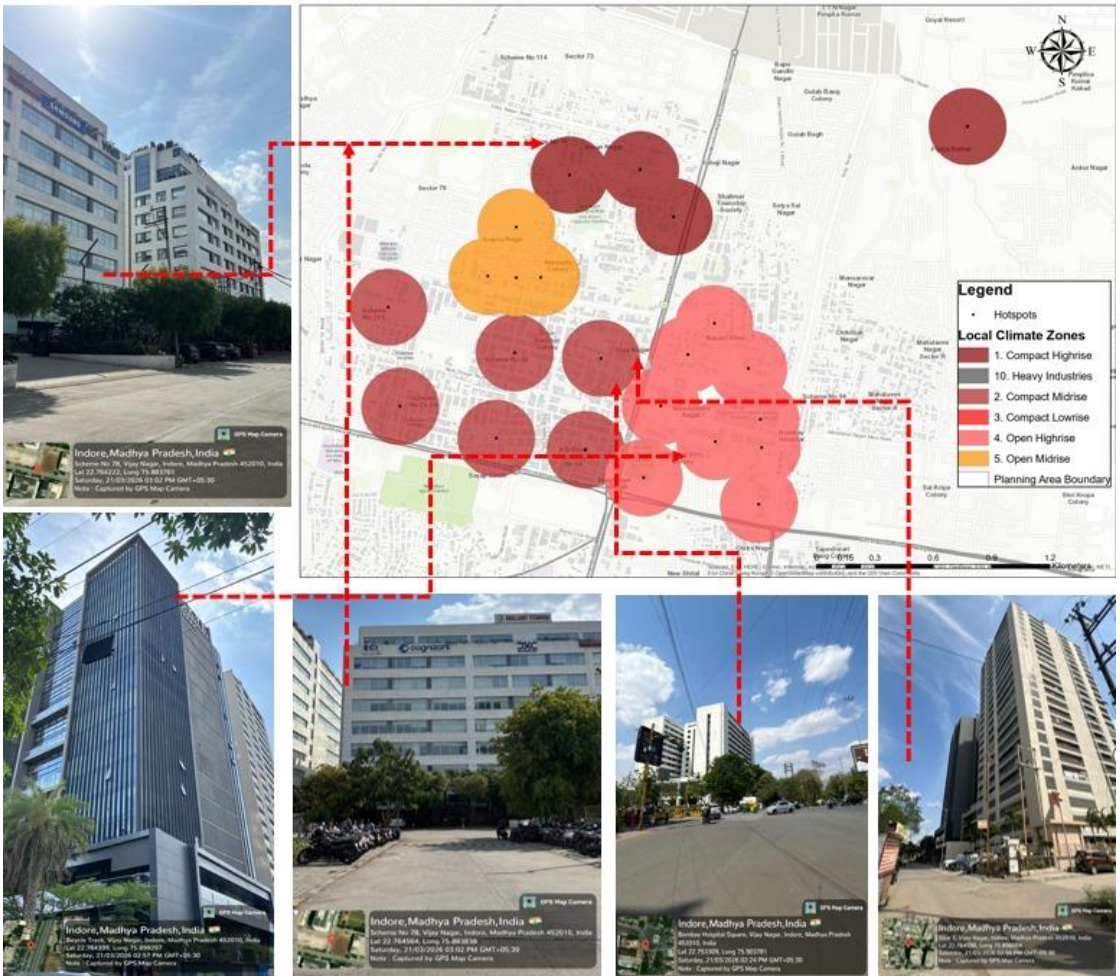


Figure 17 Hotspot Area (LCZ 1,2,3 &4) *Source:- Author*

The hotspot areas are primarily concentrated in densely built-up urban regions, where compact development patterns significantly increase surface temperatures. LCZ 1 and LCZ 2 exhibit the highest heat intensity due to the presence of compact high-rise and mid-rise buildings, limited open spaces, and extensive impervious surfaces. Reduced vegetation cover and large paved areas further intensify the Urban Heat Island (UHI) effect by absorbing and retaining heat. Commercial corridors and mixed-use zones

emerge as major thermal hotspots because of continuous human activity, traffic concentration, and dense infrastructure. Additionally, high building density restricts natural airflow and traps heat within the urban environment, leading to elevated thermal stress. Field observations also indicate dense construction, glass façades, and minimal green cover in these areas. The findings suggest that rapid urbanization in Indore is directly contributing to the expansion and intensity of thermal hotspot zones.

4.9.3 Identification of Core Heat Hotspots areas (Open Midrise and Highrise)

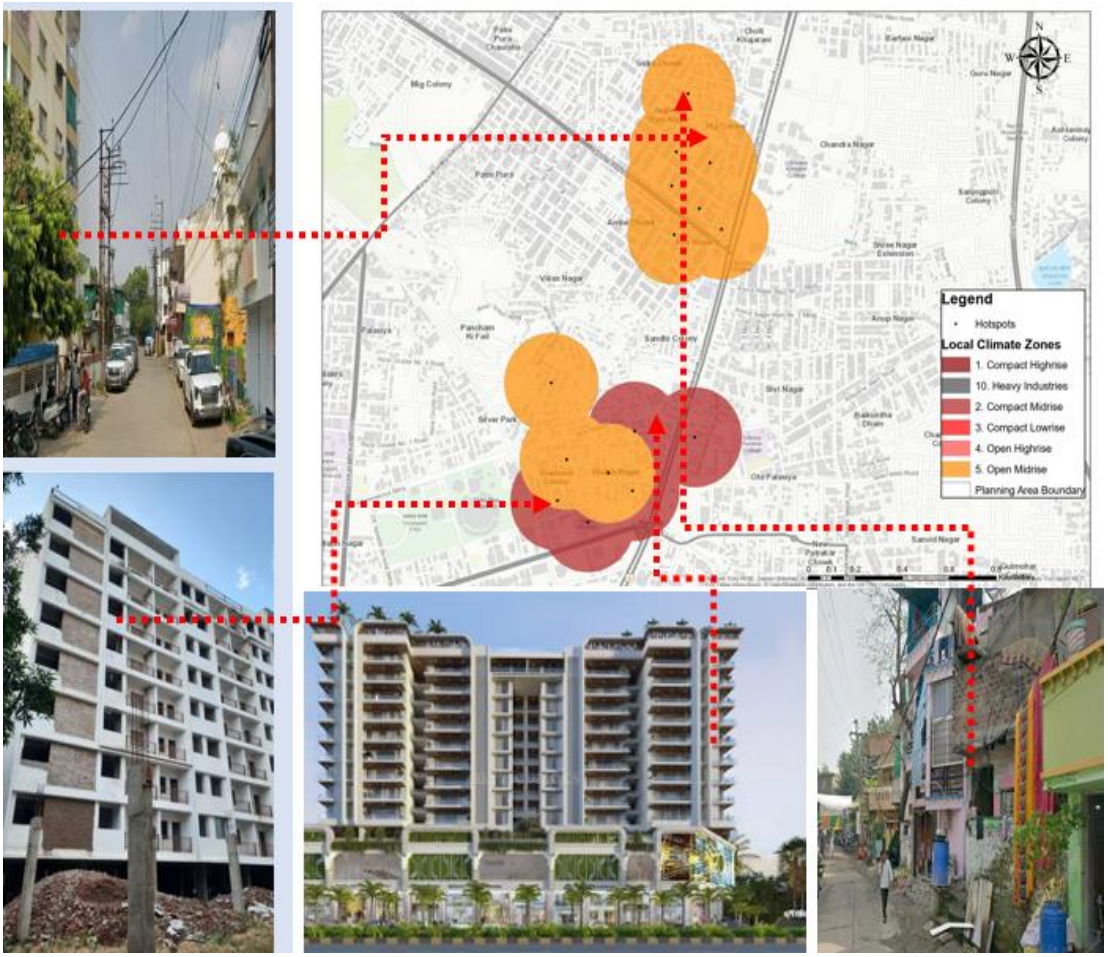


Figure 18 Heat Hotspots areas (Open Midrise and Highrise) *Source :- Author*

The map illustrates the spatial relationship between identified thermal hotspots and Local Climate Zones (LCZs) within the study area. The hotspot clusters are predominantly concentrated around LCZ 1 (Compact High-Rise), LCZ 2 (Compact Mid-Rise), and LCZ 3 (Compact Low-Rise) zones, indicating that densely built urban environments experience higher thermal intensity. These areas are characterized by high building density, limited vegetation, and extensive impervious surfaces, which contribute significantly to heat accumulation and the Urban Heat Island (UHI) effect.

The highlighted hotspot corridors also correspond to major urban activity zones and transportation routes, where continuous built surfaces and restricted airflow further intensify surface temperatures. In contrast, areas with relatively lower building compactness and more open spaces exhibit reduced hotspot intensity. The analysis demonstrates that compact urban morphology and rapid urbanization are key drivers of thermal stress within the planning area, emphasizing the need for climate-responsive planning strategies such as increasing green cover, improving ventilation corridors, and promoting sustainable urban design.

4.9.4 Identification of Core Heat Hotspots Using LCZ Analysis

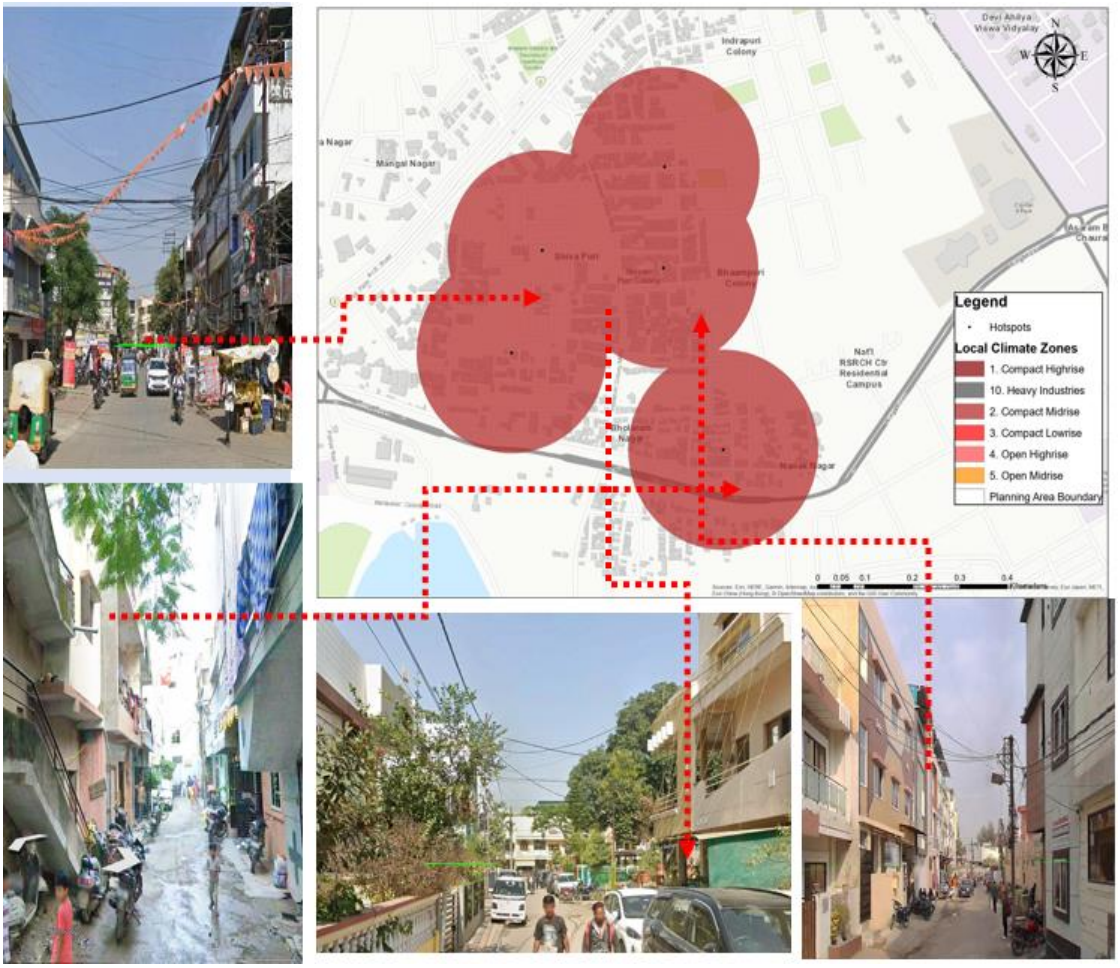


Figure19 Hotspot Area Compact Midrise *Source :- Author*

Narrow streets and dense settlements are characterized by high building density and limited open spaces, which restrict natural airflow and ventilation. These conditions lead to heat trapping within the urban environment, resulting in higher surface temperatures and increased thermal discomfort.

4.9.5 Identification of Core Heat Hotspots (LCZ 10)



Figure 20 Heavy industrial areas LCZ 10 (Heavy Industry) *Source :- Author*

SR Compound Industrial Area is primarily characterized by industrial and warehouse activities, consisting of factories, godowns, and logistics facilities. The area is located near Dewas Naka within the industrial zone of Indore rather than in the central urban core. Due to the presence of large industrial structures, extensive paved surfaces, high anthropogenic heat emissions, and limited vegetation cover, the area is classified under LCZ 10 (Heavy Industry). This LCZ category represents industrial landscapes with significant thermal intensity and reduced environmental cooling effects.

The industrial nature of the zone also results in significant anthropogenic heat emissions generated from industrial processes, vehicles, and energy consumption. Limited green spaces and reduced shading further intensify the thermal environment. As a result, the area experiences comparatively higher land surface temperatures, making it an important zone for urban heat assessment and climate-responsive planning interventions.

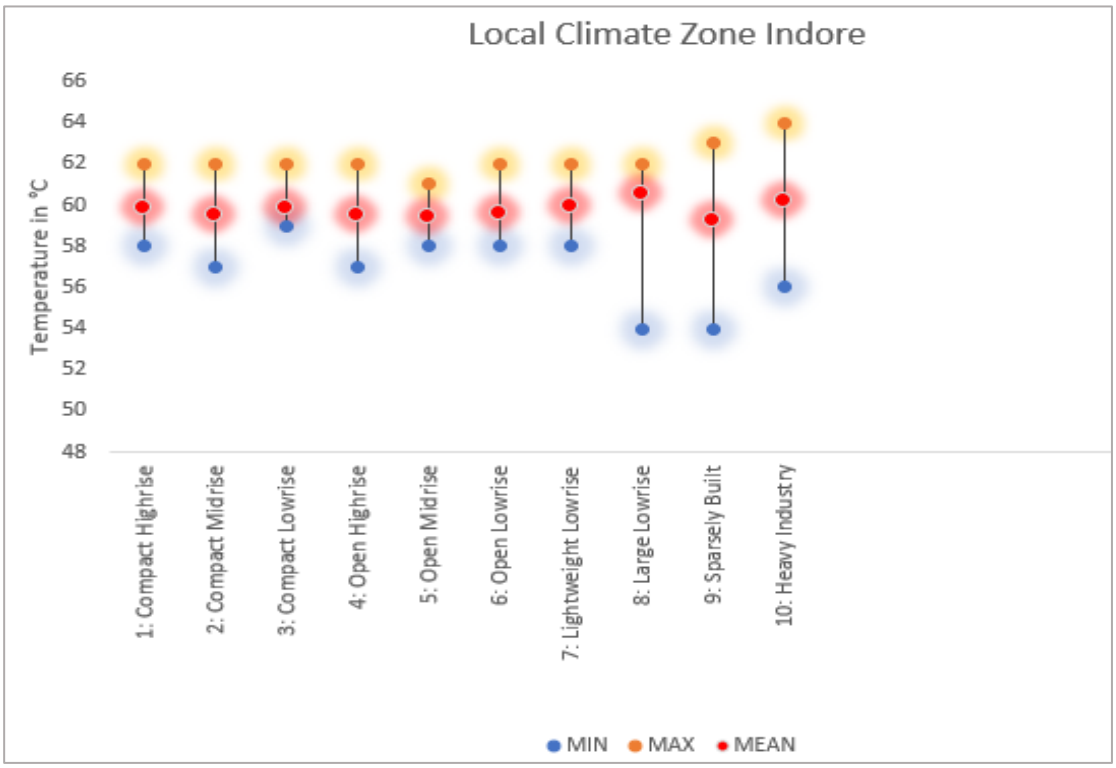


Figure 21 Local Climate Zone Indore *Source -Author*

The compact built-up zones, particularly LCZ 1 to LCZ 3, exhibit the highest thermal intensity with mean temperatures ranging between approximately 59°C and 61°C. These zones are characterized by dense urban construction, high building compactness, and extensive impervious surfaces, which contribute to significant heat retention and reduced cooling potential. LCZ 7 (Lightweight Low-Rise) also demonstrates relatively high mean and maximum temperatures, indicating that informal or densely packed low-rise settlements are highly heat-prone due to limited vegetation and poor ventilation conditions. Industrial areas classified under LCZ 10 record some of the highest maximum temperatures, reaching nearly 64°C, primarily because of heat-generating industrial activities, exposed roofing materials, and large paved surfaces. In contrast, vegetation-based climate zones (LCZ A–D) show comparatively lower mean and minimum temperatures ranging from about 54°C to 58°C. These areas function as natural cooling zones by reducing heat absorption and enhancing evapotranspiration, thereby helping to mitigate the Urban Heat Island effect within the study area.

4.10 Sky View Factor

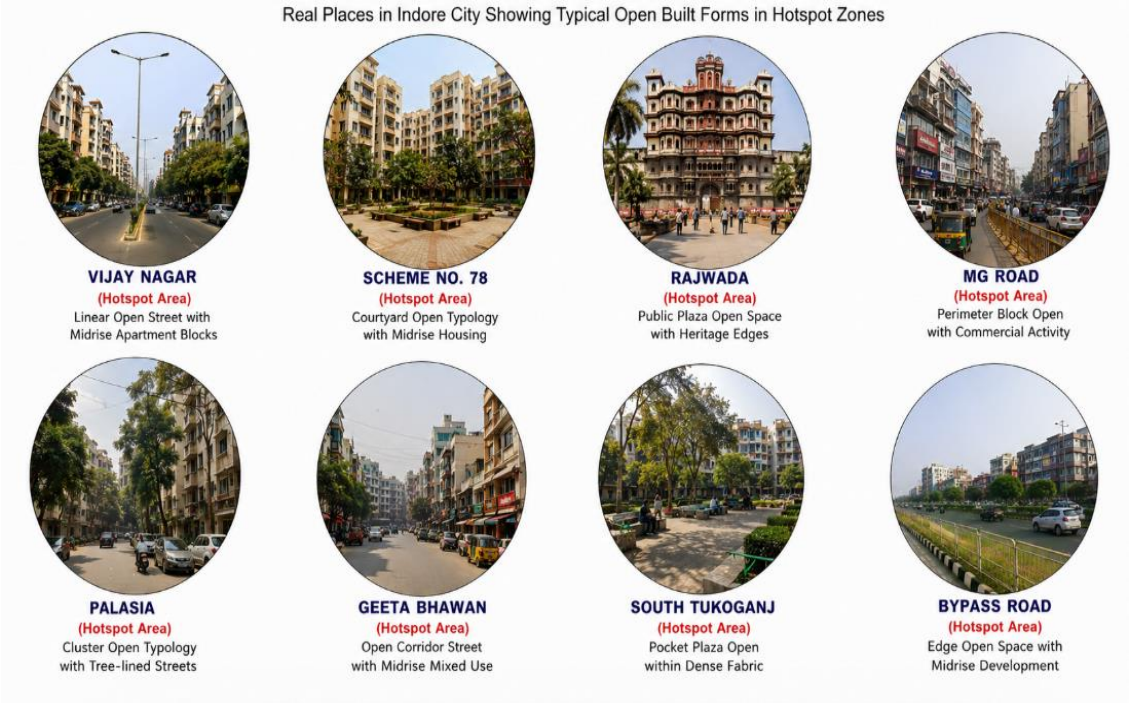


Figure 22 Sky view Factor *Source :- Author*

The Scenario of various portions of the city based on sky view factor is mentioned in Figure 21. Formula for calculation of sky view factor is as follows:

$$SVF = \frac{Visible\ Sky\ Area}{Total\ Hemisphere\ Area}$$

1. Compact High Rise for LCZ-I

The figure presents the Sky View Factor (SVF) analysis for the Compact High-Rise Local Climate Zone (LCZ 1). The results indicate predominantly low to medium SVF values, reflecting dense urban morphology and restricted sky visibility due to closely spaced high-rise buildings. Areas with lower SVF suggest reduced ventilation and greater heat retention, while relatively higher SVF zones indicate more open urban spaces with improved sky exposure. The street-view images further illustrate variations in urban enclosure and sky visibility within LCZ 1.

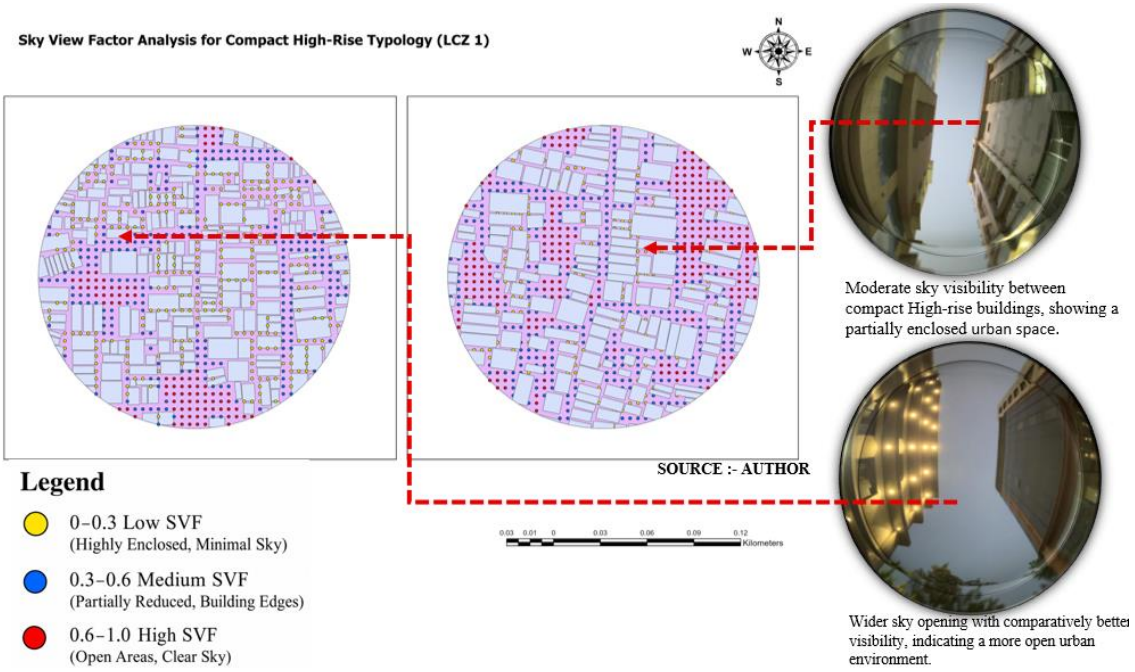


Figure 23 Compact High rise Lcz1 *Source :- Author*

The Sky View Factor (SVF) analysis for the Compact High-Rise typology (LCZ 1) highlights the spatial variation in sky visibility within densely built urban environments. The map categorizes SVF values into low (0–0.3), medium (0.3–0.6), and high (0.6–1.0) ranges, representing different levels of enclosure and openness in the urban fabric. Areas with low SVF indicate highly enclosed spaces where tall and closely spaced buildings significantly restrict sky visibility and airflow. These zones are more prone to heat retention and reduced thermal comfort due to limited ventilation and trapped radiation.

Medium SVF areas represent partially enclosed urban spaces with moderate sky exposure, generally occurring along building edges and slightly wider street corridors. In contrast, high SVF zones indicate comparatively open spaces with greater sky visibility, allowing improved airflow and better heat dissipation. The field photographs further validate the spatial conditions by showing narrow urban canyons between compact high-rise structures and relatively wider openings in certain sections. Overall, the analysis demonstrates that compact high-rise morphology strongly influences microclimatic conditions by reducing sky exposure and intensifying the Urban Heat Island (UHI) effect within dense urban areas.

2.Compact High Rise for LCZ-2

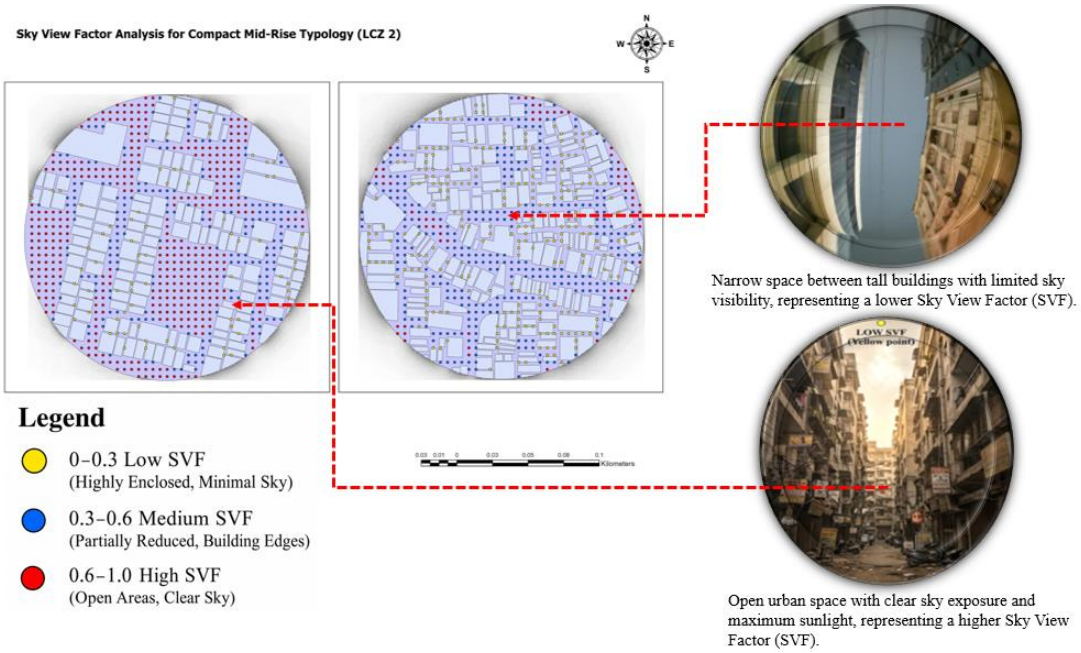


Figure 24 Compact High RiseLCZ-2 *Source :- Author*

The Sky View Factor (SVF) analysis for the Compact Mid-Rise typology (LCZ 2) illustrates the degree of sky exposure and enclosure within moderately dense urban areas. The SVF values are categorized into low (0–0.3), medium (0.3–0.6), and high (0.6–1.0) ranges, representing varying levels of openness in the urban environment. Areas with low SVF indicate narrow street canyons and closely spaced mid-rise buildings where sky visibility is significantly restricted. These enclosed urban spaces reduce natural ventilation and increase heat retention, thereby contributing to higher thermal stress and intensified Urban Heat Island (UHI) effects.

Medium SVF zones represent partially open areas with moderate sky visibility, generally observed along wider streets and building edges. High SVF areas indicate relatively open urban spaces with greater sky exposure, allowing improved airflow, sunlight penetration, and heat dissipation. The field photographs support these observations by showing both narrow built-up corridors with limited sky visibility and open spaces with clearer sky exposure. Overall, the analysis demonstrates that the compact mid-rise urban morphology strongly influences microclimatic conditions, where reduced sky visibility and dense building arrangements contribute to increased urban heat accumulation.

3.Compact low Rise for LCZ-3

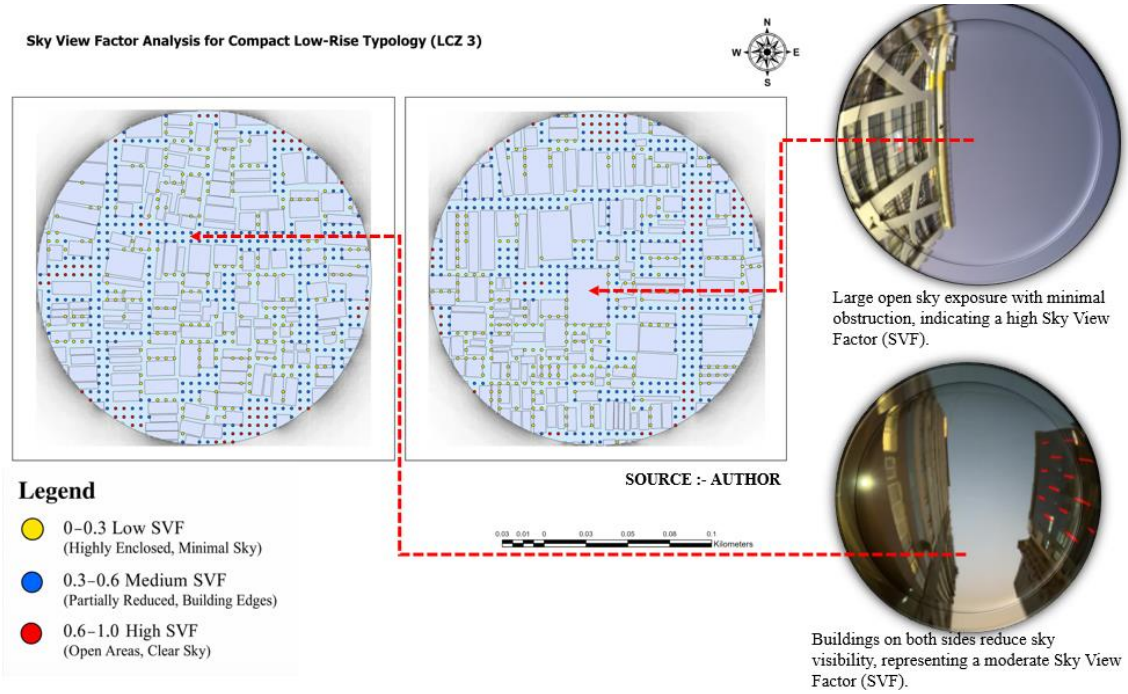


Figure 25 CompactHighRiseLCZ 3 *Source :- Author*

The Sky View Factor (SVF) analysis for the Compact Low-Rise Typology (LCZ 3) illustrates the degree of sky visibility within dense urban neighbourhoods characterized by closely spaced low-rise buildings and narrow streets. The analysis highlights variations in urban enclosure and openness, which directly influence microclimatic conditions such as heat retention, ventilation, and thermal comfort.

Areas represented with low SVF values **(0–0.3)** indicate highly enclosed urban spaces where buildings significantly obstruct the visible sky. These zones tend to trap heat and restrict airflow, contributing to higher surface temperatures and reduced thermal comfort.

The medium SVF range **(0.3–0.6)** represents partially open areas where moderate sky visibility exists due to wider street sections or building setbacks. These areas experience comparatively improved ventilation and balanced thermal conditions.

4.Open High-Rise Typology (LCZ4)

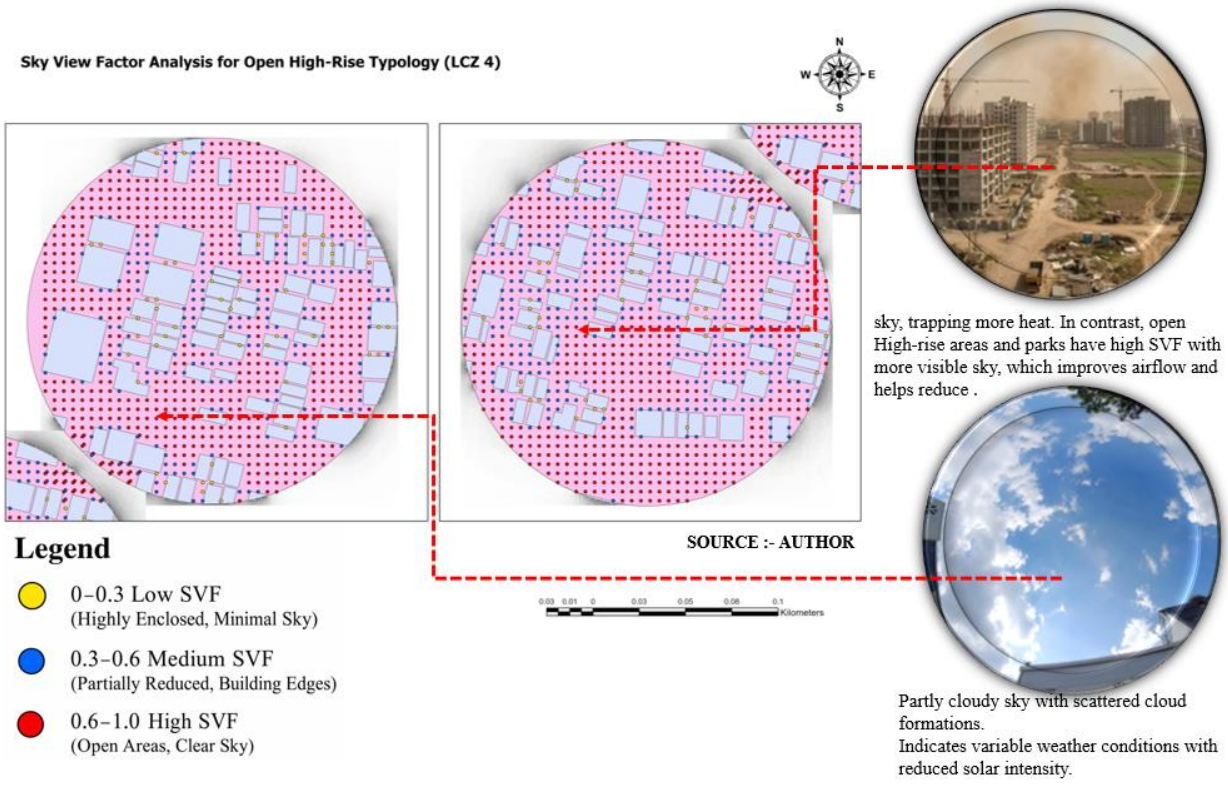


Figure 26 Compact High Rise LCZ4 *Source :- Author*

The Sky View Factor (SVF) analysis for the Open High-Rise Typology (LCZ 4) represents urban areas characterized by high-rise buildings with comparatively larger spacing and open surroundings.

The analysis shows that a large portion of the area falls under the high SVF range (0.6–1.0), indicating open spaces with significant sky exposure and minimal obstruction from surrounding structures. These areas support better natural ventilation, improved heat dissipation, and comparatively lower heat accumulation.

Areas with medium SVF values (0.3–0.6) represent partially enclosed spaces where nearby buildings moderately reduce sky visibility. Although some obstruction exists, these zones still maintain acceptable airflow and thermal comfort conditions.

Only limited portions exhibit low SVF values (0–0.3), which correspond to localized enclosed spaces between taller structures.

5.Open Mid-Rise Typology (LCZ5)

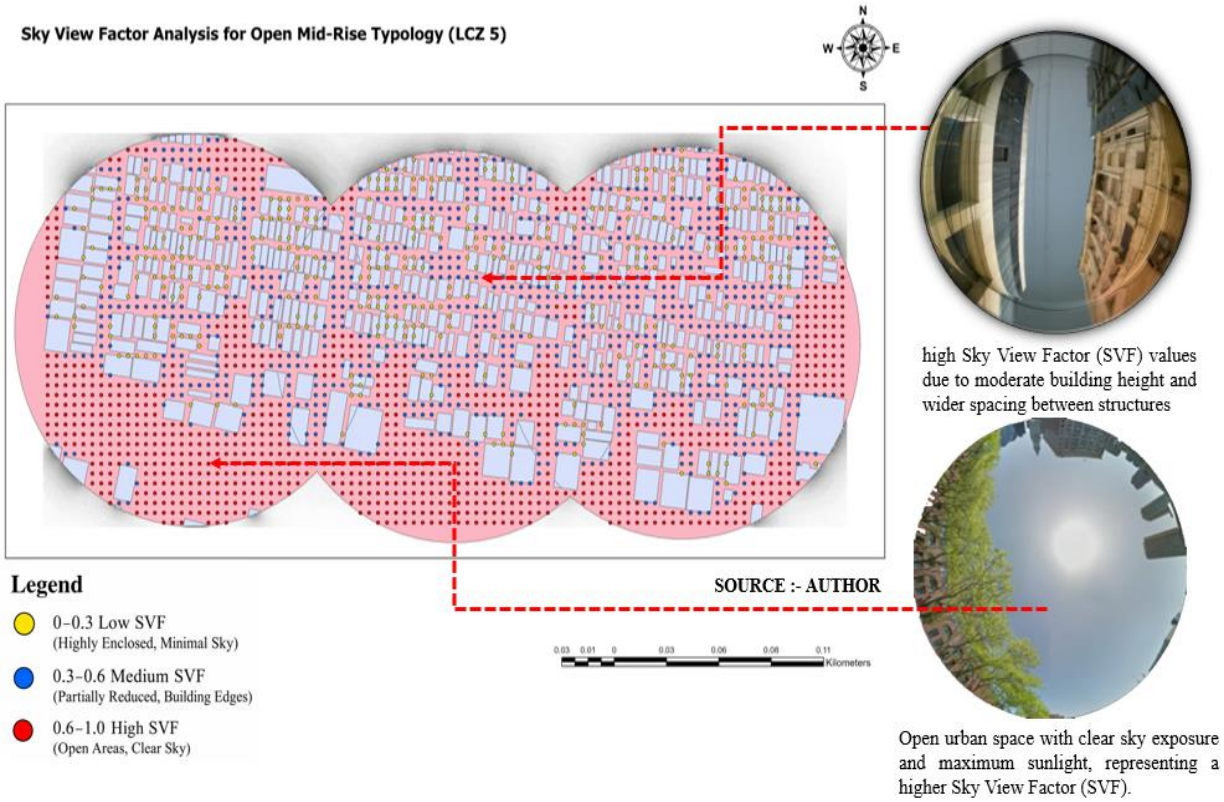


Figure 27 Open midrise typology LCZ5 *Source :- Author*

The Sky View Factor (SVF) analysis for the Open Mid-Rise Typology (LCZ 5) represents urban areas characterized by mid-rise buildings with moderate building height and comparatively wider spacing between structures.

The analysis indicates that a major portion of the area falls under the high SVF range (0.6–1.0), representing open urban spaces with greater sky exposure and minimal obstruction from surrounding buildings. These areas allow maximum sunlight penetration, improved airflow, and efficient heat dissipation due to the moderate building heights and wider street spacing. As a result, such zones experience comparatively lower heat accumulation and better outdoor thermal comfort.

Areas with medium SVF values (0.3–0.6) represent partially enclosed spaces where nearby buildings moderately restrict sky visibility. Although some obstruction and shading occur, these spaces still maintain acceptable ventilation and balanced thermal conditions because of sufficient open space between buildings.

Only a limited portion of the study area exhibits low SVF values (0–0.3), which correspond to localized enclosed pockets between closely spaced buildings or narrow street sections.

These areas experience restricted sky exposure, reduced airflow, and comparatively higher heat retention due to limited ventilation and reduced solar reflection.

5.Heavy Industry (LCZ 10)

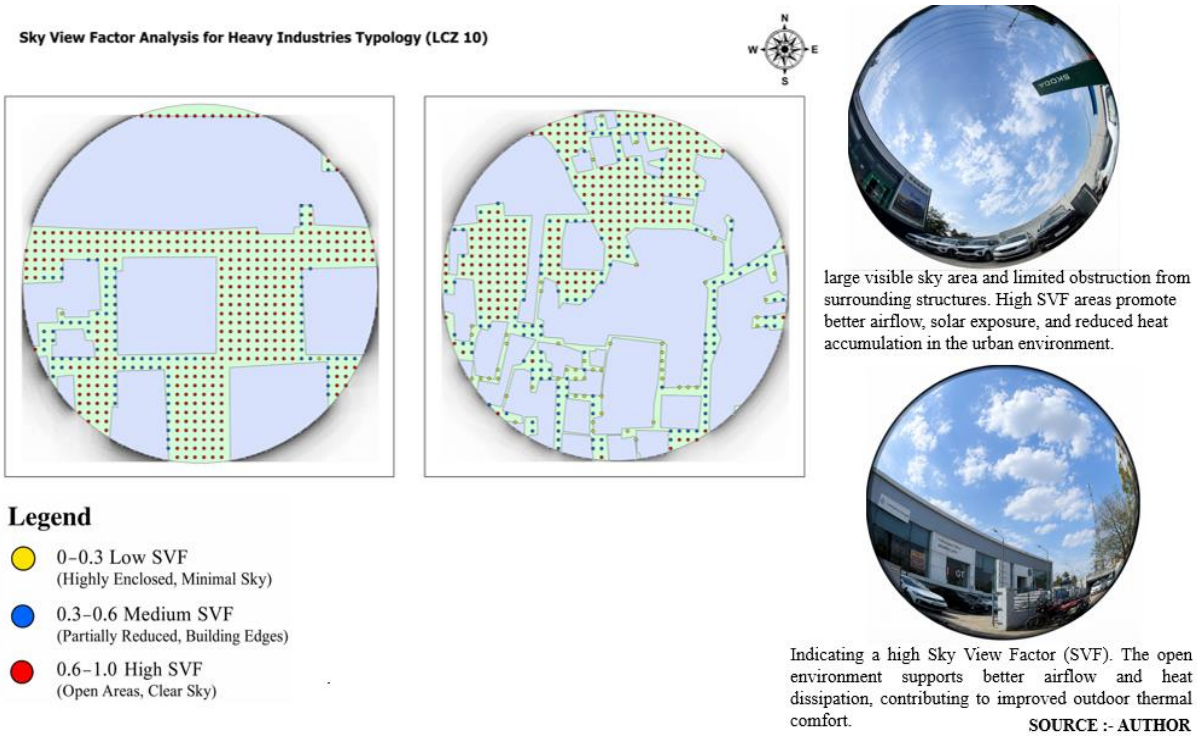


Figure 28 Heavy Industry LCZ10 *Source :- Author*

The Sky View Factor (SVF) analysis for the Heavy Industry Typology (LCZ 10) represents industrial areas characterized by large industrial buildings, warehouses, and comparatively open surroundings with wider spacing between structures.

The analysis shows that a significant portion of the area falls within the high SVF range (0.6–1.0), indicating extensive open spaces with greater sky visibility and minimal obstruction from surrounding structures. These areas allow better solar exposure, enhanced airflow, and efficient heat dissipation, which help reduce localized heat accumulation within the industrial environment. The wider spacing between industrial units also supports improved outdoor thermal conditions and ventilation.

Areas with medium SVF values (0.3–0.6) correspond to partially enclosed industrial zones where large buildings and boundary structures moderately restrict sky exposure. Although some obstruction exists, these areas still maintain adequate airflow and thermal exchange due to the relatively open layout of the industrial typology.

Only limited portions exhibit low SVF values (0–0.3), representing enclosed pockets between large industrial structures or narrow service corridors. These zones may experience reduced ventilation, restricted sky visibility, and comparatively higher heat retention because of the obstruction created by bulky industrial buildings and paved surfaces.

4.11 All LCZ-Based Urban Thermal Pattern Analysis

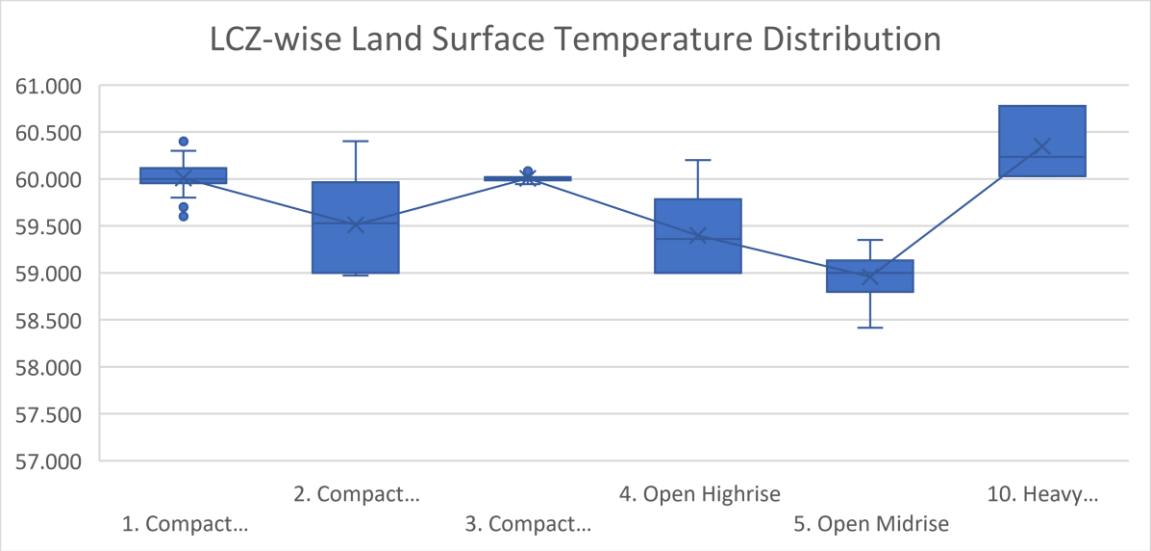


Figure 29 LCZ-wise Land Surface Temperature Distribution *Source-Author*

This box plot shows the variation of surface temperature across different Local Climate Zones (LCZ). Heavy industrial areas record the highest temperatures, while Open Midrise zones show comparatively lower temperatures the graph highlights how different urban forms influence thermal conditions within the study area. Formula for Calculation of these Factors as follows:

1. $Normalised\ Difference\ Vegetation\ Index\ (NDVI) = \frac{NIR-Red}{NIR+Red}$
2. $Normalised\ Differece\ Built\ Index\ (NDBI) = \frac{SWIR-NIR}{SWIR+NIR}$
3. $Building\ Surface\ Fraction\ (BSF) = \frac{Building\ Footprint\ Area}{Total\ Site\ Area}$

4. $Pervious\ Surface\ Fraction\ (PSF) = \frac{Pervious\ Surface\ Area}{Total\ Site\ Area}$

5. $Impervious\ Surface\ Fraction\ (ISF) = \frac{Impervious\ Surface\ Area}{Totsl\ Site\ Area}$

6. $Sky\ View\ Factor\ (SVF) = \frac{Visible\ Sky\ Area}{Total\ Hemisphere\ Area}$

I. **N**DBI is used to identify and map built-up urban areas from satellite imagery, helping to assess the extent of urbanization and impervious surfaces.

II. BSF represents the proportion of building-covered area within the total site area, indicating the intensity of built-up development.

III. PSF indicates the proportion of permeable surfaces such as vegetation and open soil, which support water infiltration and cooling effects.

IV. ISF represents the percentage of hard and non-permeable surfaces such as roads and pavements, which contribute to heat absorption and runoff generation.

V. SVF measures the amount of visible sky from a ground point and reflects urban openness and ventilation conditions, influencing solar exposure and heat dissipation.

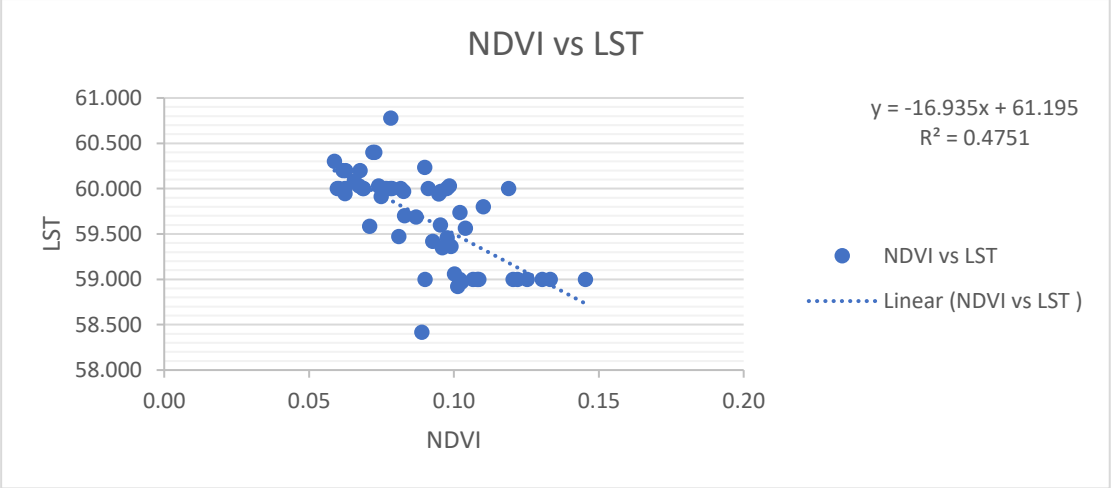


Figure 30 Relation btw NDVI V/S LST *Source-Author*

This graph shows that areas with more vegetation have lower surface temperatures. As NDVI increases, LST decreases, which clearly indicates the cooling effect of trees and green spaces in urban areas.

while areas with sparse vegetation show comparatively higher temperatures. As NDVI values increase, LST values gradually decrease, highlighting the important role of vegetation in reducing urban heat. Trees, parks, and green spaces help cool the surrounding environment through shading and evapotranspiration processes. In contrast, built-up and barren surfaces absorb and retain more heat, leading to higher temperatures. The results clearly indicate that increasing urban greenery can significantly contribute to mitigating heat stress and improving thermal comfort in urban areas.

The analysis reveals a clear inverse relationship between NDVI and Land Surface Temperature (LST). Areas with higher vegetation density generally exhibit lower surface temperatures, whereas areas with sparse vegetation or limited green cover experience higher temperatures. As NDVI values increase, LST values tend to decrease, demonstrating the cooling effect of vegetation. Green spaces, trees, and urban parks help regulate surface temperatures through shading and evapotranspiration, reducing heat accumulation in the urban environment. These findings emphasize the importance of enhancing urban green cover as an effective strategy for mitigating heat risk and improving thermal comfort within the city.

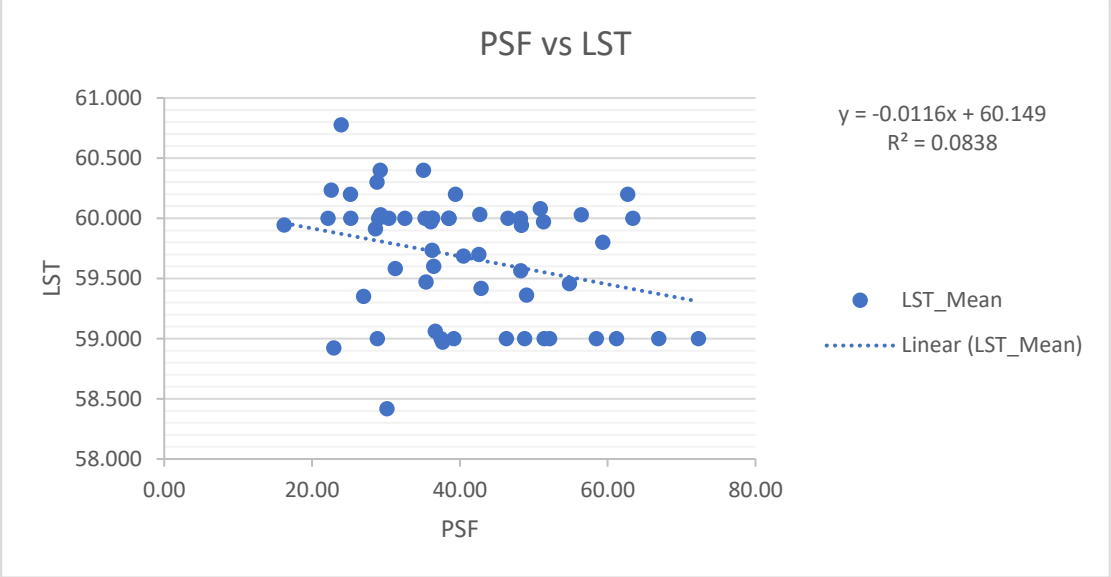


Figure 31 Relation btw PSF V/S LST *Source- Author*

The graph shows a slight decrease in temperature with an increase in pervious surfaces (PSF). However, the relationship is weak, meaning pervious surfaces provide some cooling effect but not very strongly in this study.

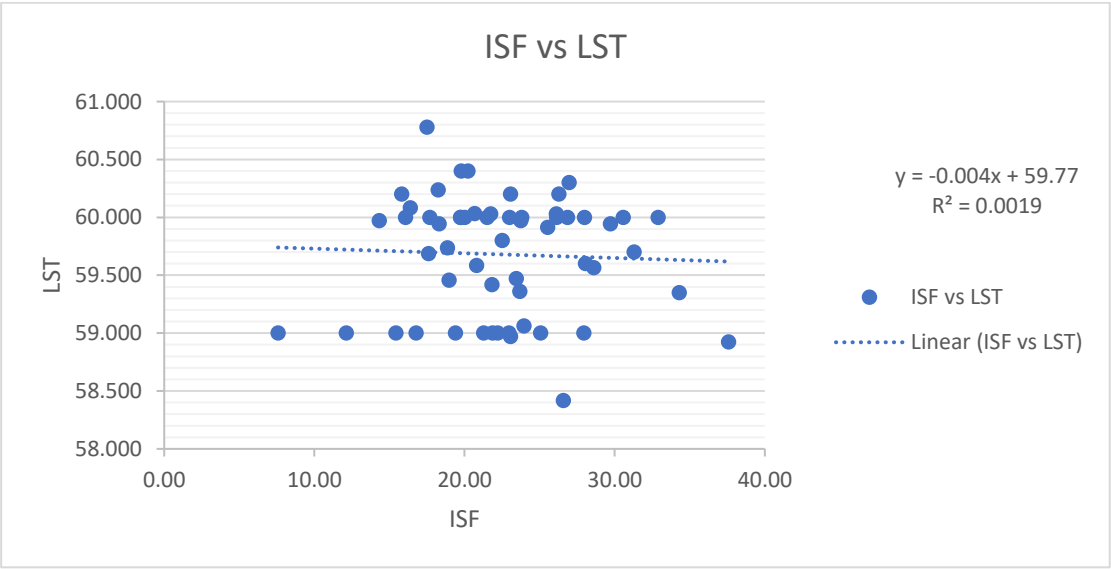


Figure 32 Relation btw ISF V/S LST *Source- Author*

This graph shows that Impervious Surface Fraction (has very little impact on Land Surface Temperature (LST).

The relationship is almost flat, which means changes in paved or built up surfaces do not strongly affect temperature in this dataset.

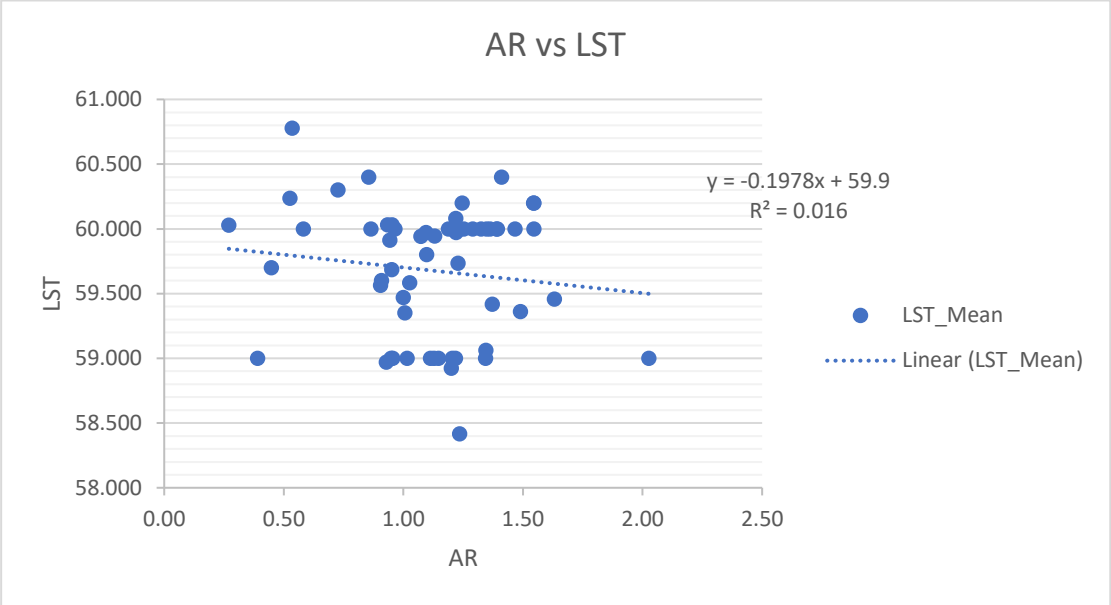


Figure 33 Relation btw ARV/SLST *Source- Author*

This graph shows a very weak relationship between Aspect Ratio (AR) and Land Surface Temperature (LST) The nearly flat trendline indicates that changes in street or building height to width ratio do not significantly affect surface temperature in this study.

The nearly flat trendline suggests that variations in the height-to-width ratio of streets and buildings have minimal influence on surface temperature within the study area. Unlike vegetation or built-up density, AR does not appear to be a major controlling factor for urban heat in this case. The weak correlation indicates that other parameters such as vegetation cover, impervious surfaces, and building density may have a stronger impact on temperature distribution. This also suggests that the thermal environment of the area is influenced more by land cover characteristics than by street canyon geometry alone.

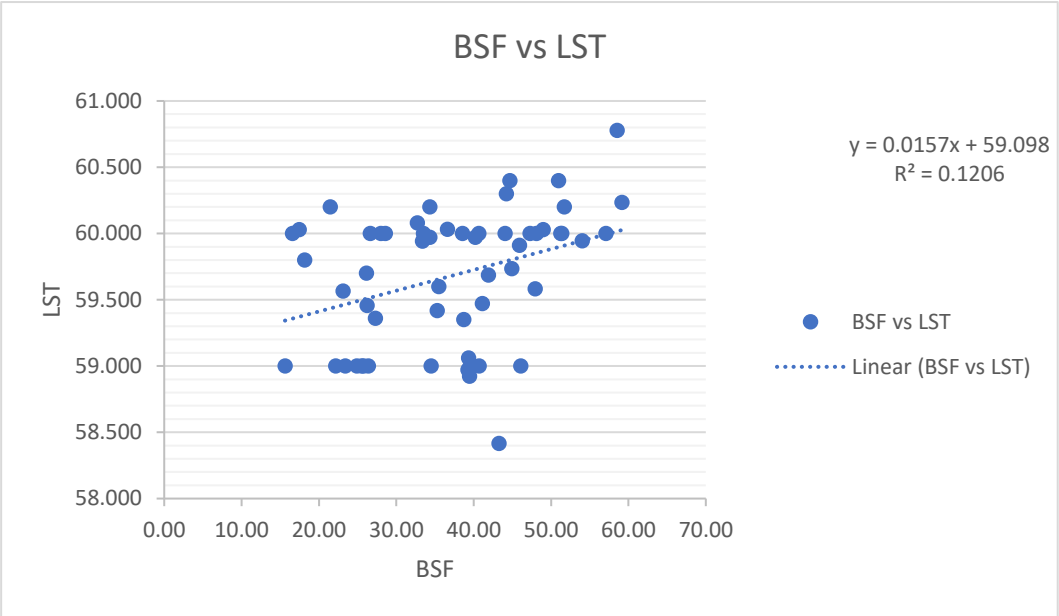


Figure 34 Relation btw BSFV/SLST *Source- Author*

This graph shows a very weak relationship between Aspect Ratio (AR) and Land Surface Temperature (LST). The nearly flat trendline indicates that changes in street or building height to width ratio do not significantly affect surface temperature in this study.

Indicates a very weak correlation between Aspect Ratio (AR) and Land Surface Temperature (LST). The almost flat trendline suggests that variations in the building height-to-street width ratio have little impact on surface temperature patterns in the study area. The results imply that AR alone is not a significant factor influencing urban heat conditions. Instead, other urban characteristics such as vegetation cover, building density, and impervious surfaces may play a more dominant role in controlling temperature distribution. This weak relationship highlights that street canyon geometry has limited influence on LST within the selected urban environment.

4.11.1 LCZ I-Based Urban Thermal Pattern Analysis

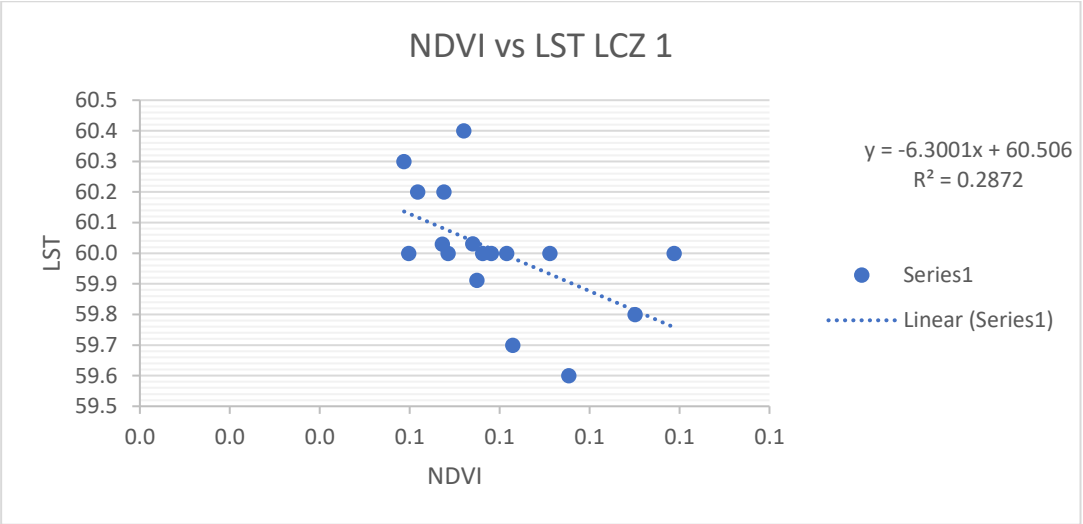


Figure 35 Relation btw NDVI V/S LST *Source- Author*

This graph shows that areas with more vegetation have lower surface temperatures As NDVI increases, LST decreases, which highlights the cooling effect of green spaces in compact urban areas.

This graph demonstrates a clear negative relationship between NDVI and Land Surface Temperature (LST), indicating that areas with higher vegetation cover generally experience lower surface temperatures. As NDVI values increase, LST values gradually decrease, highlighting the significant cooling effect of vegetation within compact urban environments. Green spaces such as parks, trees, and planted areas help reduce heat through shading and evapotranspiration processes, thereby improving the microclimatic conditions of the surrounding area. In contrast, densely built-up zones with limited vegetation tend to absorb and retain more solar radiation, resulting in higher surface temperatures. The findings emphasize the importance of increasing urban greenery as an effective strategy for mitigating urban heat and enhancing thermal comfort in compact city areas.

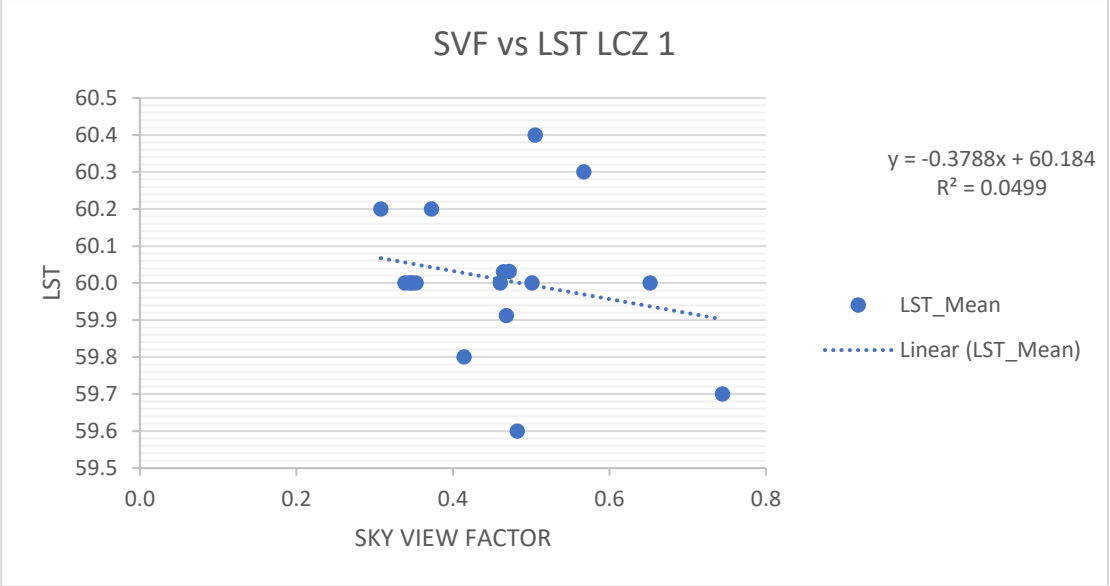


Figure 36 Relation btw SVFV/SLST *Source- Author*

This graph indicates very little relationship between Sky View Factor (SVF) and surface temperature. The nearly flat trendline shows that sky visibility does not significantly affect temperature in this dataset.

Indicates a very weak relationship between Sky View Factor (SVF) and Land Surface Temperature (LST). The nearly flat trendline suggests that variations in sky visibility have minimal influence on surface temperature within the study area. Although SVF is generally associated with urban openness and ventilation, the results show that it does not significantly control temperature patterns in this dataset. Areas with higher or lower sky exposure exhibit only minor differences in surface temperature, indicating that other urban parameters may have a stronger effect on thermal conditions. Factors such as vegetation cover, impervious surfaces, and built-up density are likely to play a more dominant role in influencing urban heat distribution. The findings suggest that SVF alone is not a sufficient indicator for explaining temperature variability in the selected urban environment.

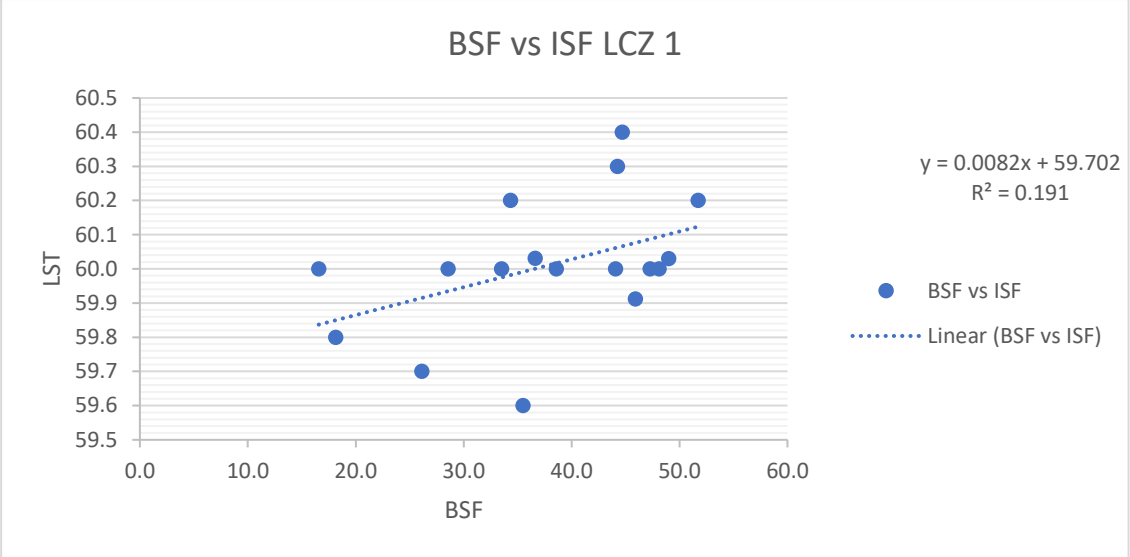


Figure 37 Relation btw BSFV/SISF *Source- Author*

This graph indicates that areas with more bare soil tend to have slightly higher temperatures. The positive trend shows that exposed soil surfaces can increase heat in the area.

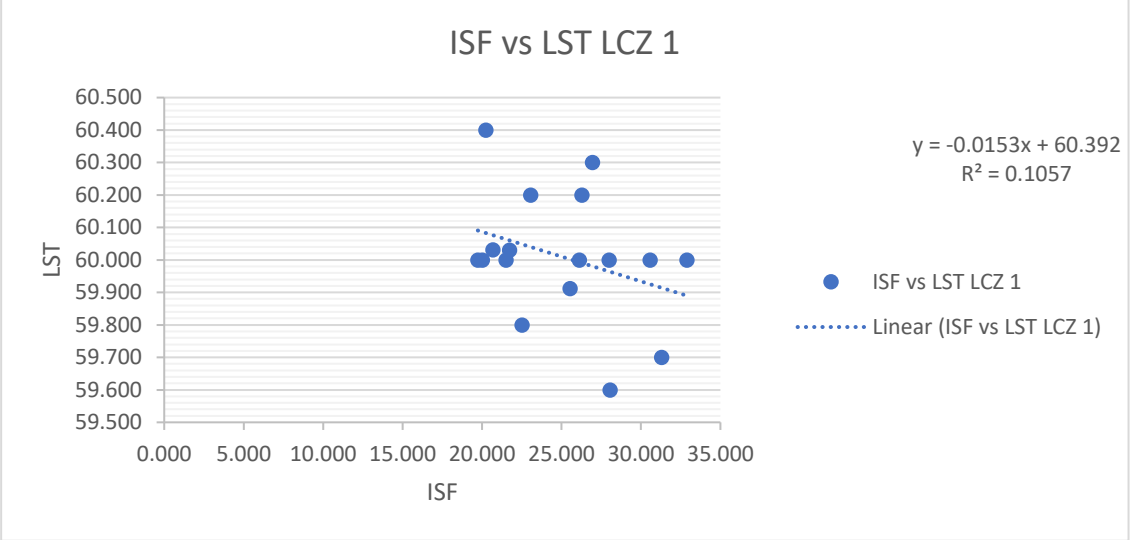


Figure 38 Relation btw ISFV/SLST *Source- Author*

The ISF vs LST analysis for LCZ 1 shows a weak negative relationship, indicating that as the Impervious Surface Fraction (ISF) increases, the Land Surface Temperature (LST) slightly decreases, although the correlation is very low ($R^2 = 0.1057$).

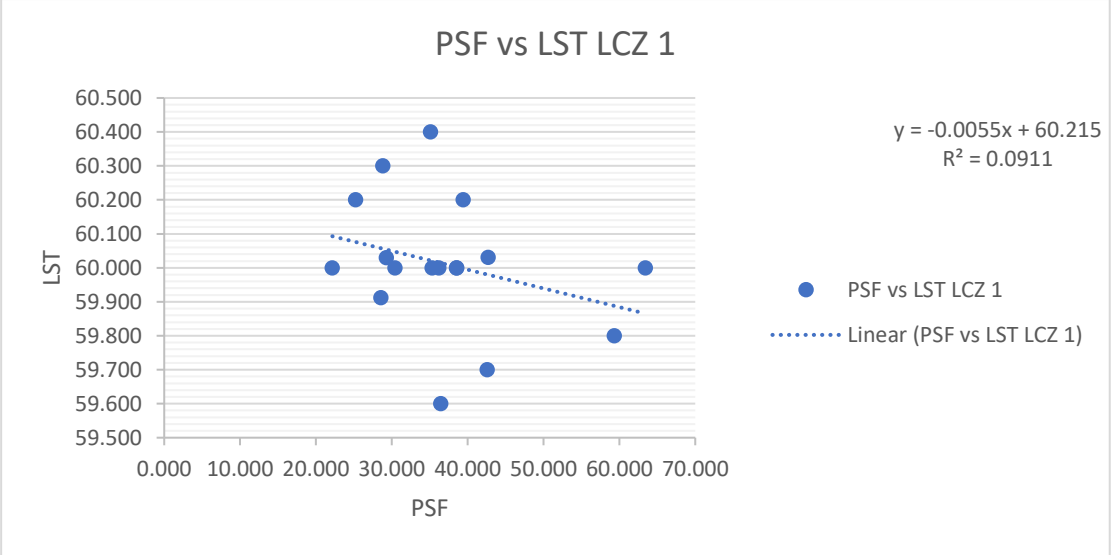


Figure 39 Relation btw PSFV/SLST *Source- Author*

This graph shows a slight decrease in temperature with an increase in pervious surfaces. It suggests that water absorbing surfaces provide a small cooling effect, but the relationship is weak in this study.

shows a slight negative relationship between Pervious Surface Fraction (PSF) and Land Surface Temperature (LST). As the proportion of pervious surfaces increases, surface temperature tends to decrease slightly, indicating a limited cooling effect within the study area. Pervious surfaces such as vegetation, soil, and open green spaces allow water infiltration and support evapotranspiration, which can help reduce heat accumulation. However, the weak trendline suggests that the influence of PSF on temperature is relatively small compared to other urban factors. The findings indicate that although water-absorbing surfaces contribute to cooling, their overall impact on urban heat patterns in this study is not very strong. Other parameters such as built-up density, impervious surfaces, and vegetation cover may have a greater influence on temperature distribution.

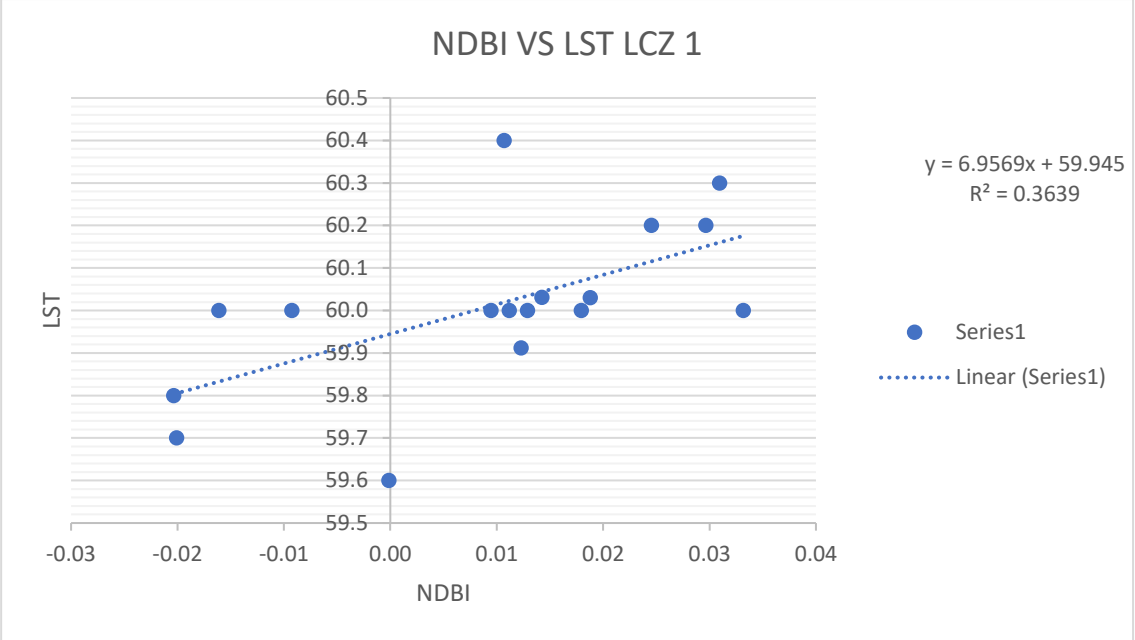


Figure 40 Relation btw NBDIV/SLST *Source- Author*

This graph shows that areas with higher built up density have higher surface temperatures As NDBI increases, LST also increases, indicating that buildings and concrete surfaces contribute to heat generation in LCZ 1.

4.11.2 LCZ II-Based Urban Thermal Pattern Analysis

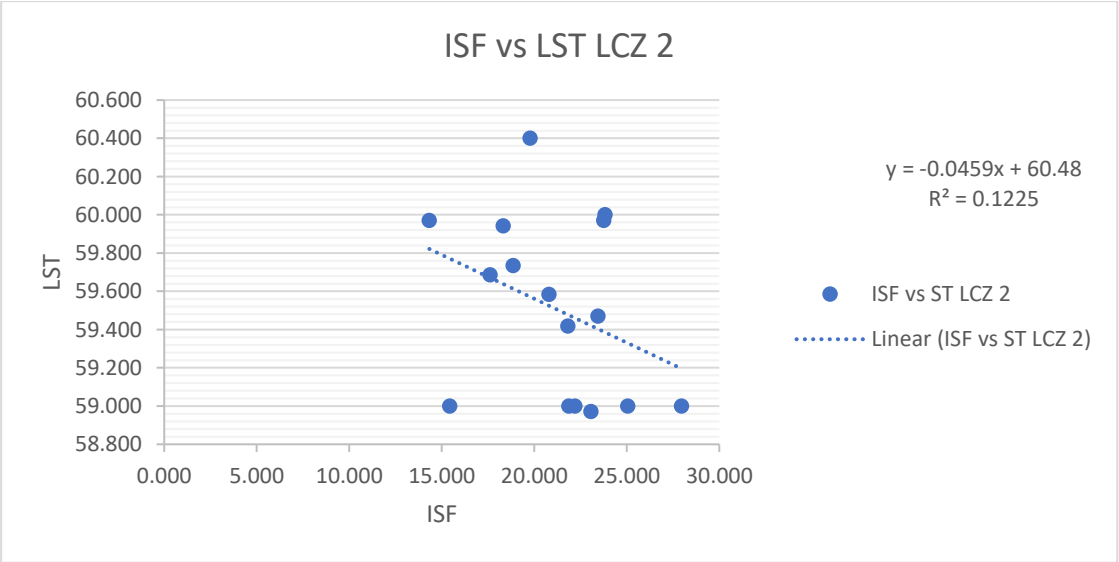


Figure 41 RelationbtwISFV/SLST *Source-Author*

This graph shows that areas with higher built up density have higher surface temperatures As NDBI increases, LST also increases, indicating that buildings and concrete surfaces contribute to heat generation in LCZ 1.

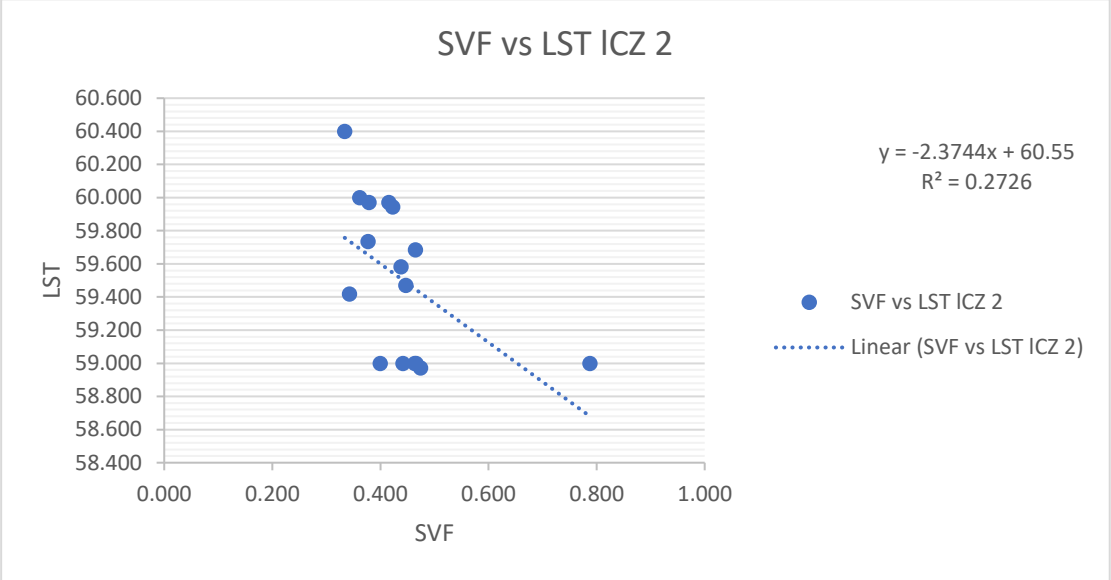


Figure 42 RelationbtwSVFV/SLST *Source-Author*

The SVF vs LST analysis for LCZ 2 shows a moderate negative relationship, indicating that higher Sky View Factor (SVF) values are associated with lower Land Surface Temperature (LST) due to improved sky exposure and ventilation ($R^2 = 0.2726$).

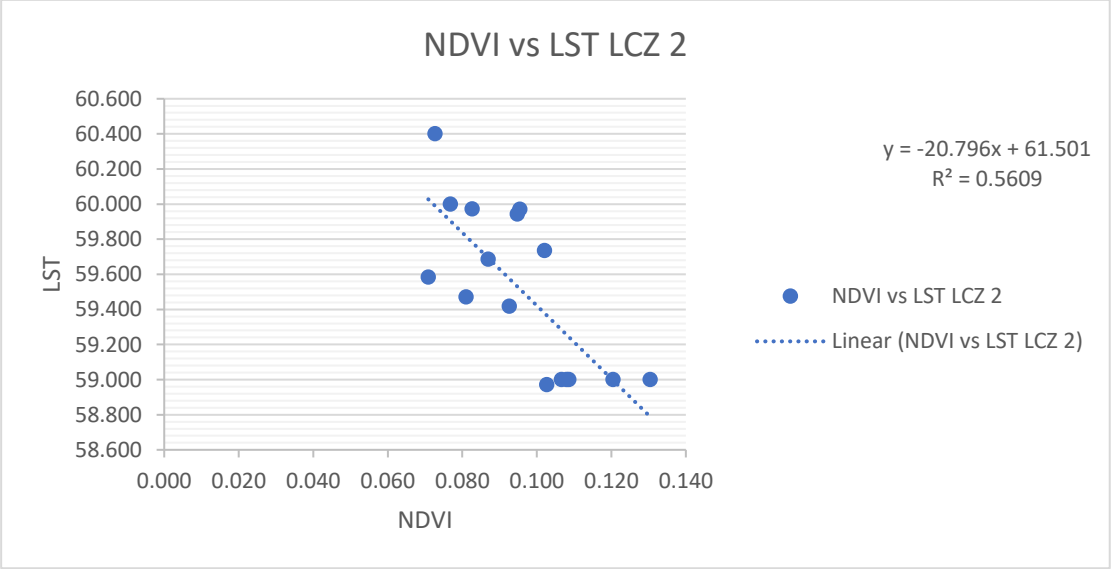


Figure 43 Relation btw NDVIV/SLST *Source- Author*

This graph shows a slight decrease in temperature with an increase in pervious surfaces. It suggests that water absorbing surfaces provide a small cooling effect, but the relationship is weak in this study.

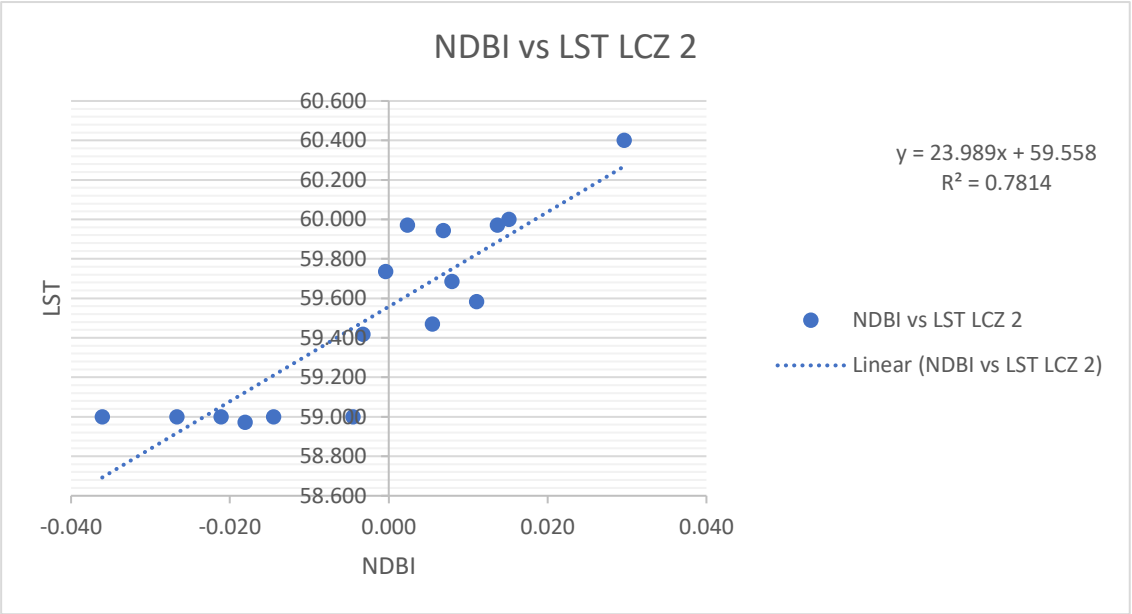


Figure 44 RelationbtwNBDIV/SLST *Source- Author*

This graph indicates very little relationship between Sky View Factor (SVF) and surface temperature. The nearly flat trendline shows that sky visibility does not significantly affect temperature in this dataset.

This graph indicates a very weak relationship between Sky View Factor (SVF) and Land Surface Temperature (LST). The nearly horizontal trendline suggests that variations in sky visibility have little influence on surface temperature patterns within the study area. Although SVF is commonly associated with urban openness, solar exposure, and ventilation, the results show that it does not significantly affect thermal conditions in this dataset. Areas with both high and low sky exposure exhibit similar temperature values, indicating limited temperature variation due to SVF alone. This suggests that other urban parameters, such as vegetation cover, built-up density, and impervious surfaces, may have a stronger impact on urban heat distribution. The findings highlight that sky visibility is not a dominant factor controlling surface temperature in the selected urban environment.

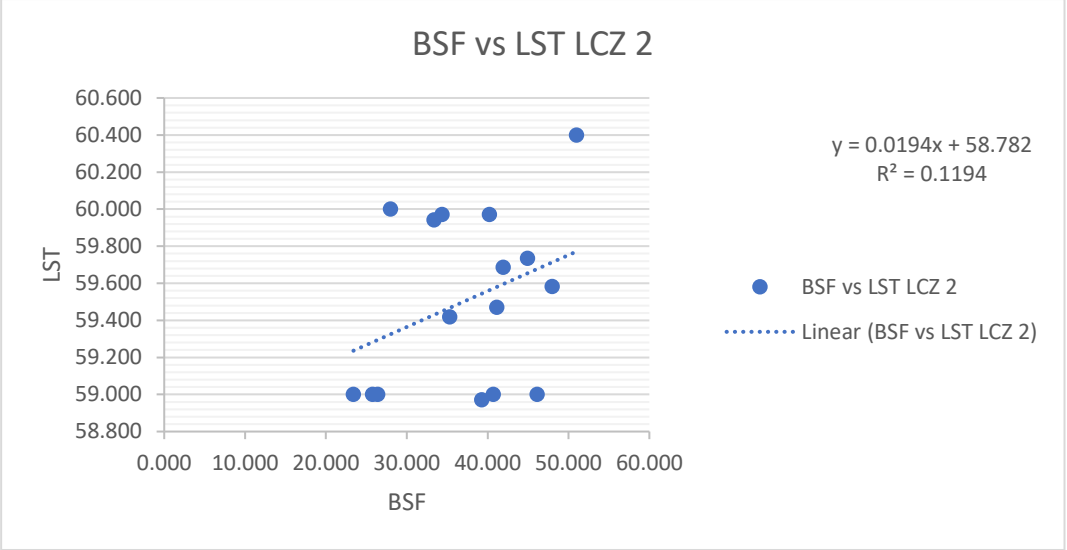


Figure 45 Relation btw BSFIV/SLST *Source- Author*

This graph shows that areas with more bare soil have slightly higher surface temperatures The upward trend indicates that exposed soil surfaces can increase heat in LCZ 2.

The scatter plot illustrates the relationship between Building Surface Fraction (BSF) and Land Surface Temperature (LST) within LCZ 2 (Compact Midrise). The positive trendline indicates that LST tends to increase as BSF increases. This suggests that areas with a higher proportion of building coverage generally experience higher surface temperatures due to increased heat absorption and reduced cooling effects. However, the relatively low coefficient of determination ($R^2 = 0.1194$) indicates a weak relationship, implying that other factors such as vegetation cover, impervious surfaces, and urban geometry also influence temperature variations within LCZ 2. Overall, the results suggest that greater building density contributes to higher heat intensity, although its impact is moderate.

4.11.3 LCZ III-Based Urban Thermal Pattern Analysis

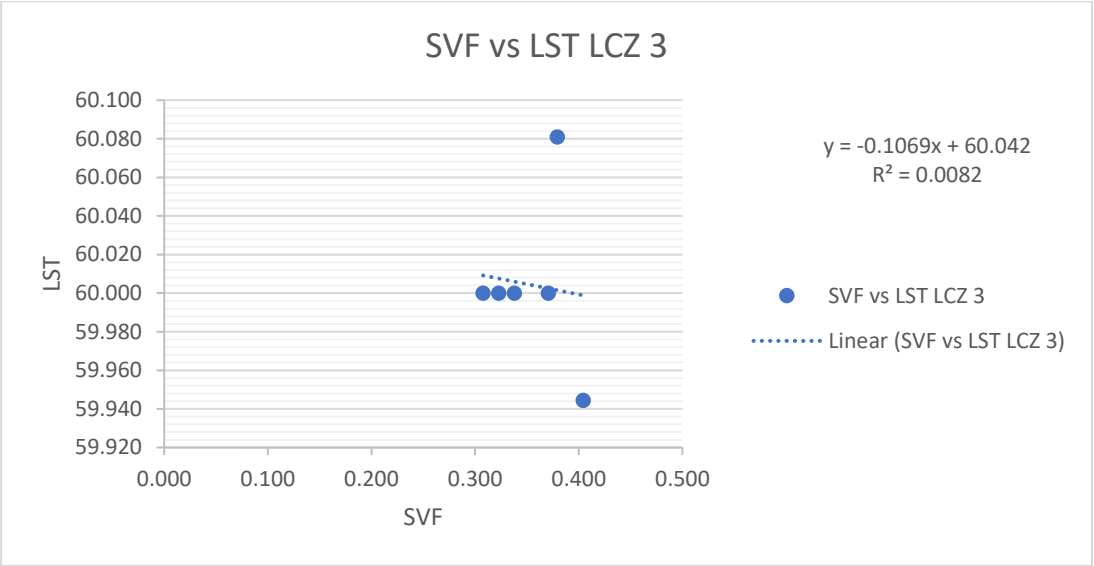


Figure 46 Relation btw SVFV/SLST *Source- Author*

This graph shows very little relationship between Sky View Factor (SVF) and surface temperature the flat trendline indicates that sky visibility does not significantly affect temperature in LCZ 3

The scatter plot illustrates the relationship between Sky View Factor (SVF) and Land Surface Temperature (LST) within LCZ 3 (Compact Low-Rise). The trendline shows a very slight negative relationship, indicating that areas with higher sky visibility tend to have marginally lower surface temperatures. However, the extremely low coefficient of determination ($R^2 = 0.0082$) suggests that SVF has a negligible influence on LST in this LCZ. The data points are closely clustered around similar temperature values, indicating limited temperature variation across different SVF conditions. Overall, the results imply that sky visibility alone does not significantly affect surface temperature in LCZ 3, and other urban form characteristics are likely more influential in determining heat patterns.

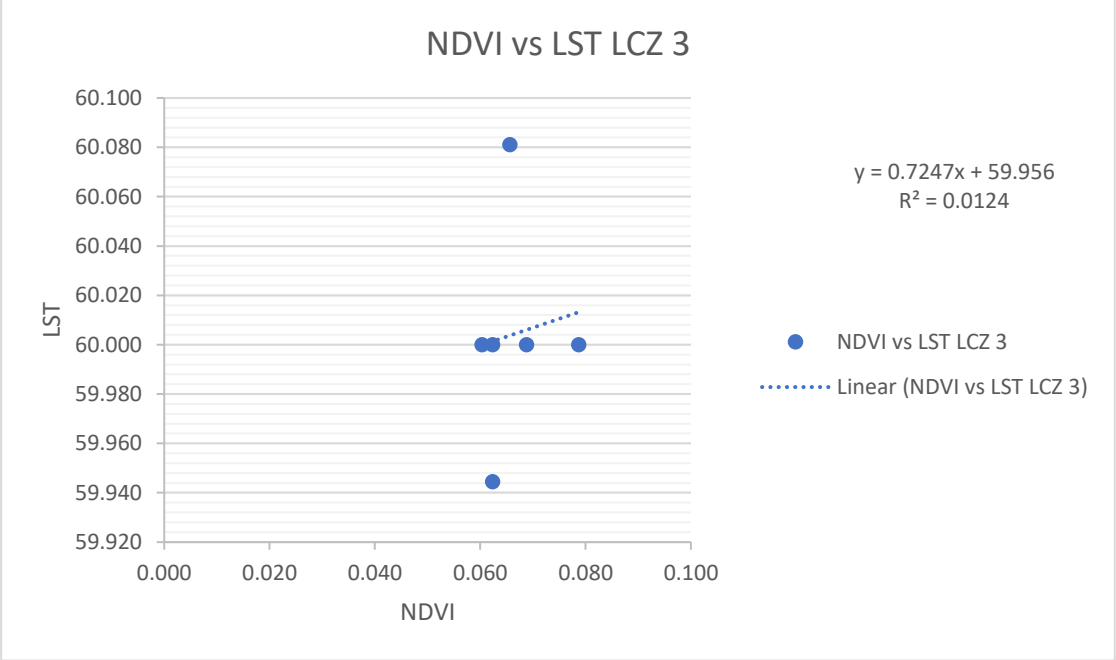


Figure 47 Relation btw NDVI V/SLST *Source- Author*

This graph shows no strong relationship between vegetation cover and surface temperature. The data suggests that greenery is not creating a noticeable cooling effect in this zone.

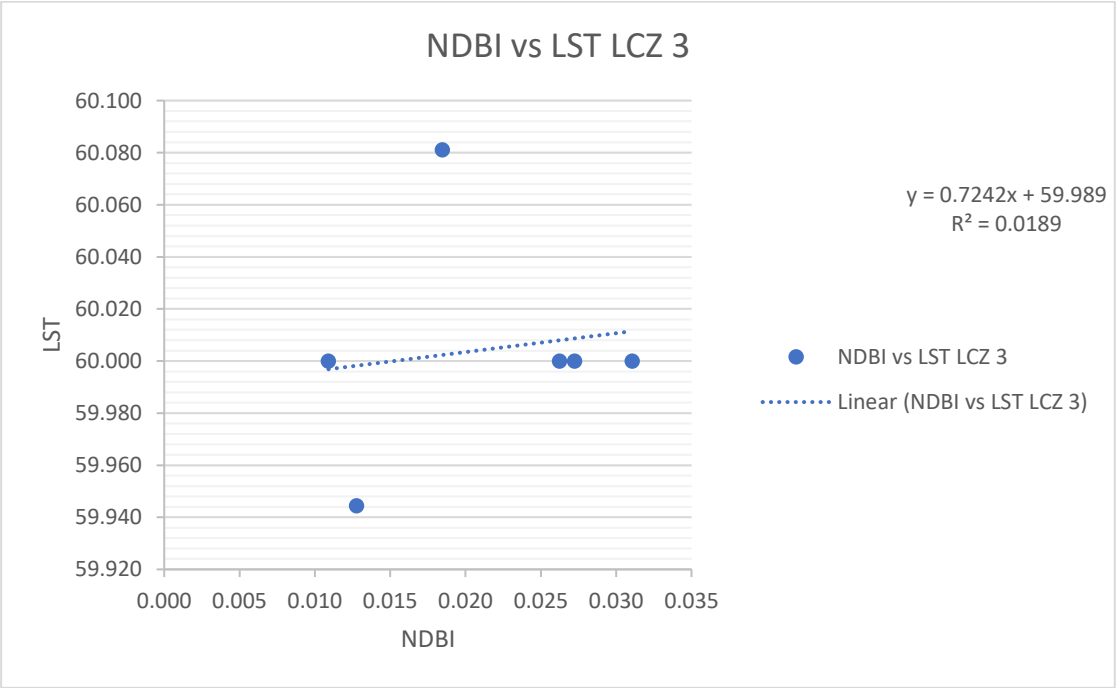


Figure 48 RelationbtwNBDIV/SLST *Source- Author*

This graph indicates that built up density has very little impact on surface temperature in LCZ 3. The trendline shows no clear increase in temperature with higher built up areas.

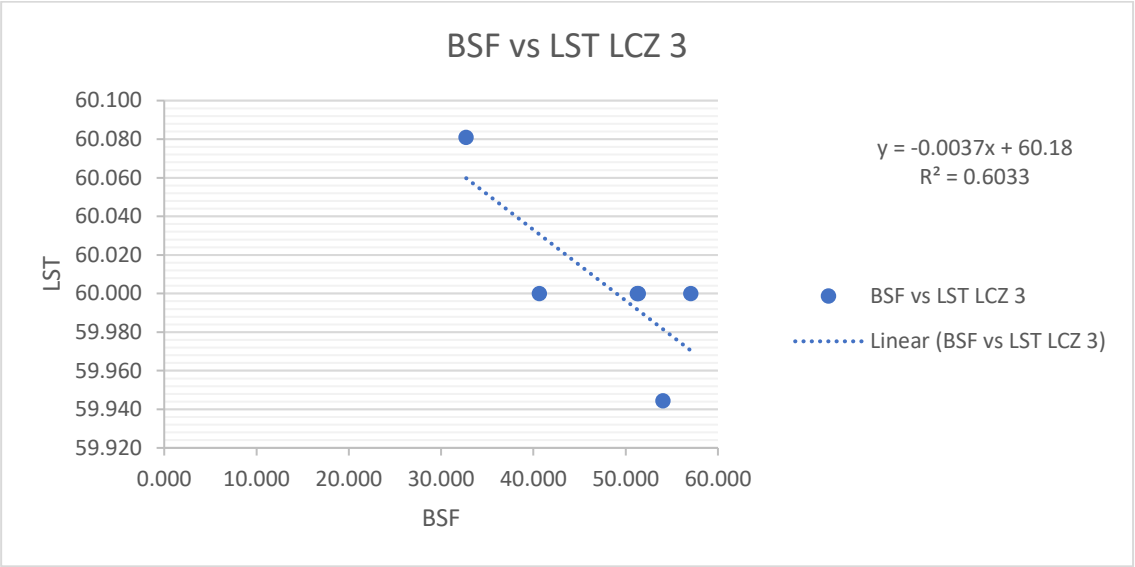


Figure 49 Relation btw BSFIV/SLST *Source-Author*

This graph shows that as building surface area increases, surface temperature slightly decreases in LCZ 3 The downward trend indicates a negative relationship between BSF and LST.

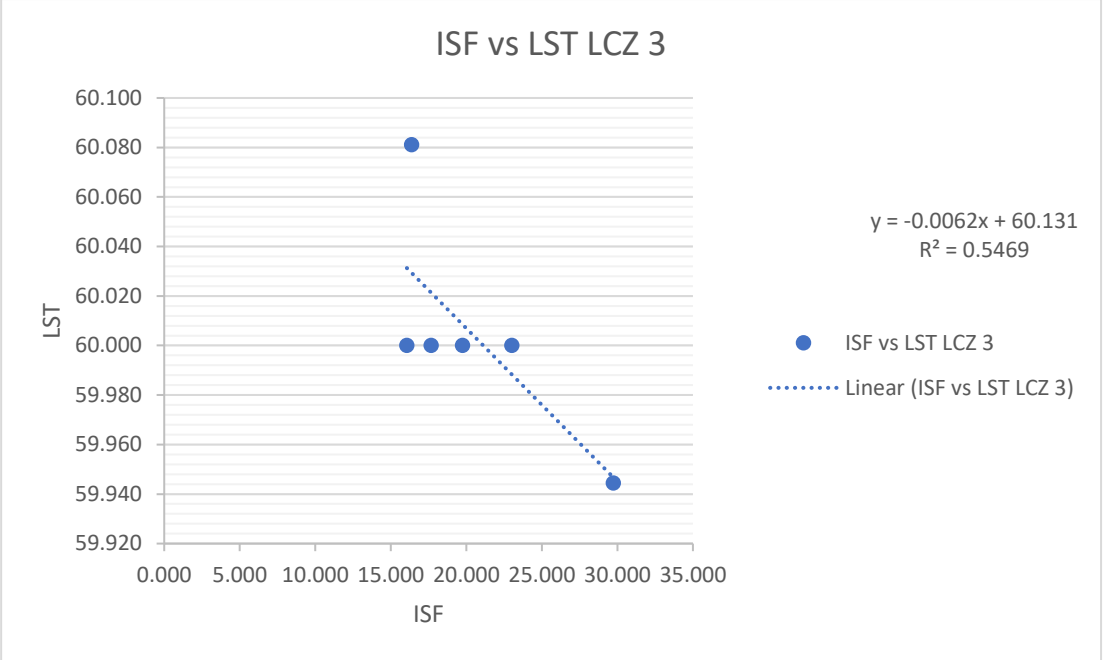


Figure 50 RelationbtwISFV/SLST *Source- Author*

This graph indicates that areas with more impervious surfaces, such as roads and paved areas, show a slight decrease in surface temperature in this dataset.

The graph shows the relationship between Impervious Surface Fraction (ISF) and Land Surface Temperature (LST) in LCZ 3 (Compact Low-Rise). The trendline has a negative slope ($y = -0.0062x + 60.131$), indicating that LST slightly decreases as ISF increases. The R^2 value of 0.5469 suggests a moderate negative relationship between ISF and LST. Most observations are concentrated around 16–24% ISF with LST values close to 60°C, while the highest ISF value (~30%) corresponds to a slightly lower temperature. This indicates that ISF has a moderate influence on surface temperature in LCZ 3, although other urban form factors may also contribute to temperature variations.

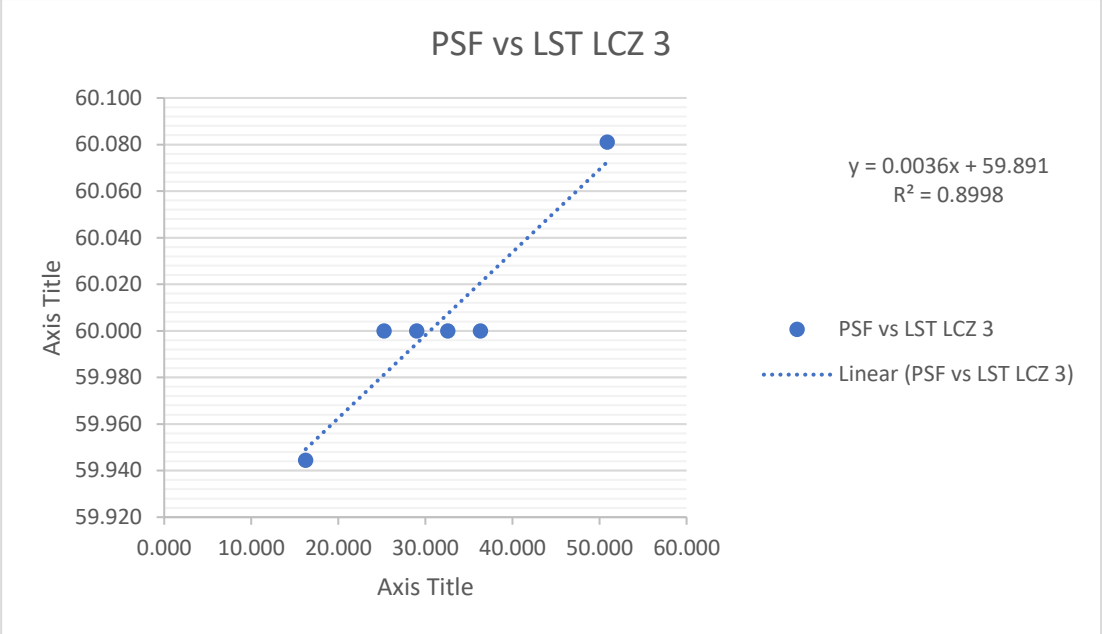


Figure 51 RelationbtwPSFV/SLST *Source- Author*

This graph shows that areas with more pervious surfaces are associated with higher surface temperatures. The strong upward trend indicates a positive relationship between PSF and LST in LCZ 3.

4.11.4 LCZ IV-Based Urban Thermal Pattern Analysis

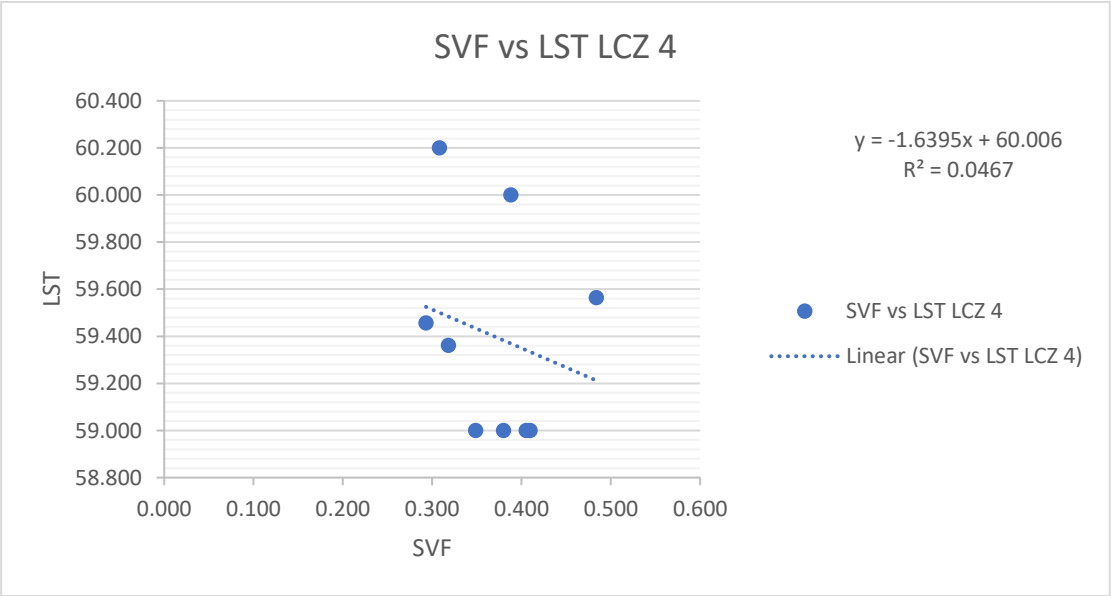


Figure 52 Relation btw SVFV/SLST *Source- Author*

This graph shows very little relationship between Sky View Factor (SVF) and surface temperature The trendline indicates that sky visibility does not significantly affect temperature in LCZ 4.

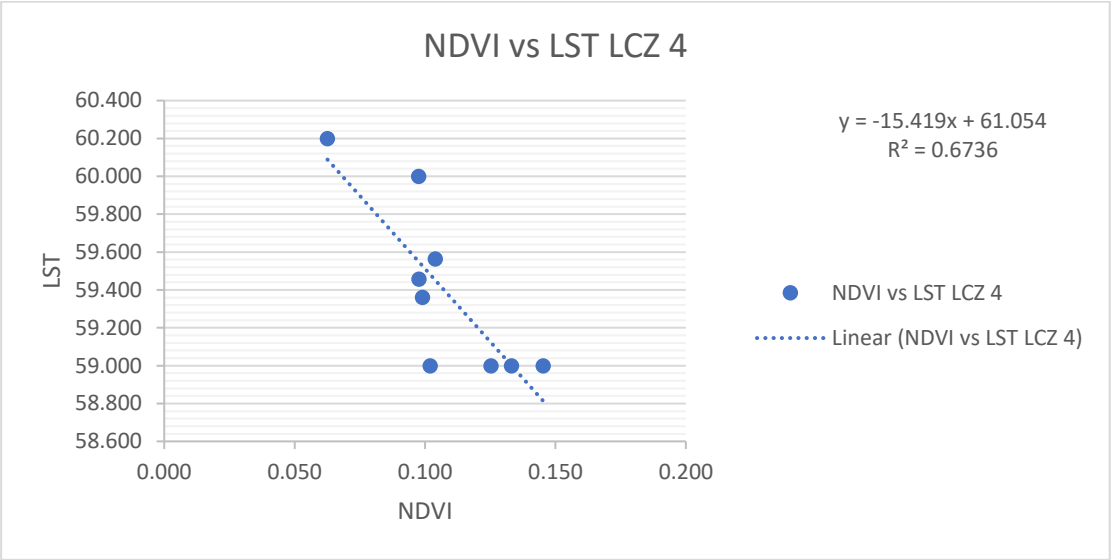


Figure 53 Relation btw NDVIV/SLST *Source- Author*

This graph shows that areas with more vegetation have lower surface temperatures. As NDVI increases, LST decreases, highlighting the strong cooling effect of greenery in LCZ 4.

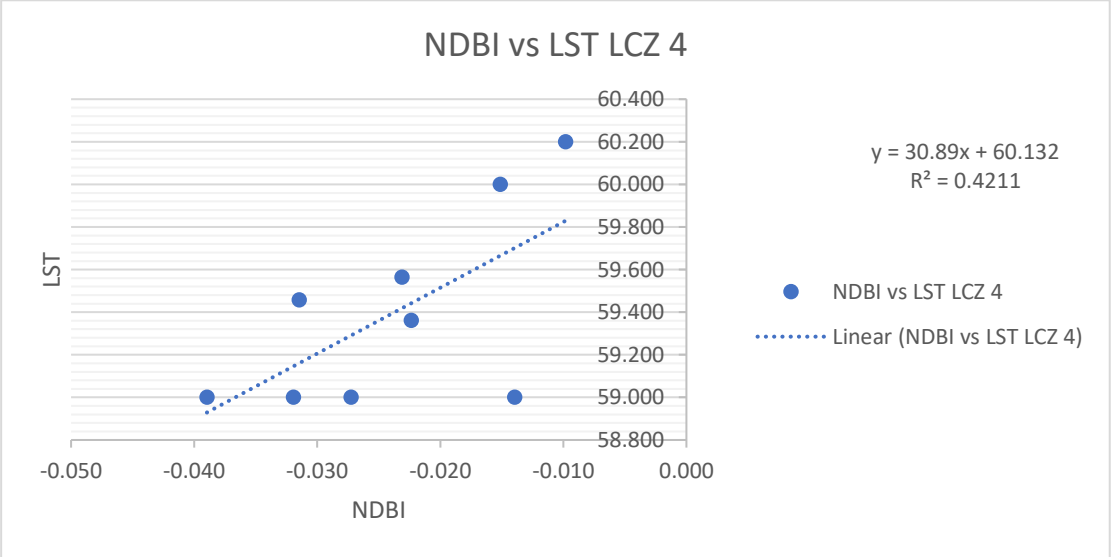


Figure 54 Relation btw NBDIV/SLST *Source- Author*

This graph indicates that areas with higher built up density experience higher surface temperatures The upward trend shows that buildings and concrete surfaces contribute to heat increase in LCZ 4.

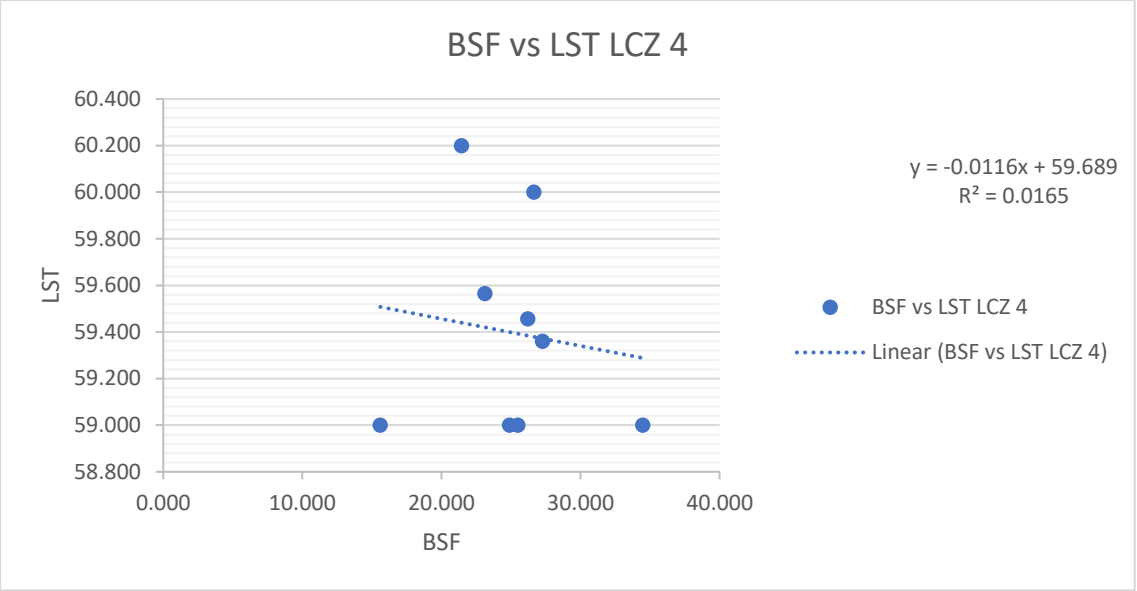


Figure 55 Relation btw BSFIV/SLST *Source- Author*

This graph shows very little relationship between Building Surface Fraction (BSF) and surface temperature. Building coverage does not significantly affect LST in this dataset.

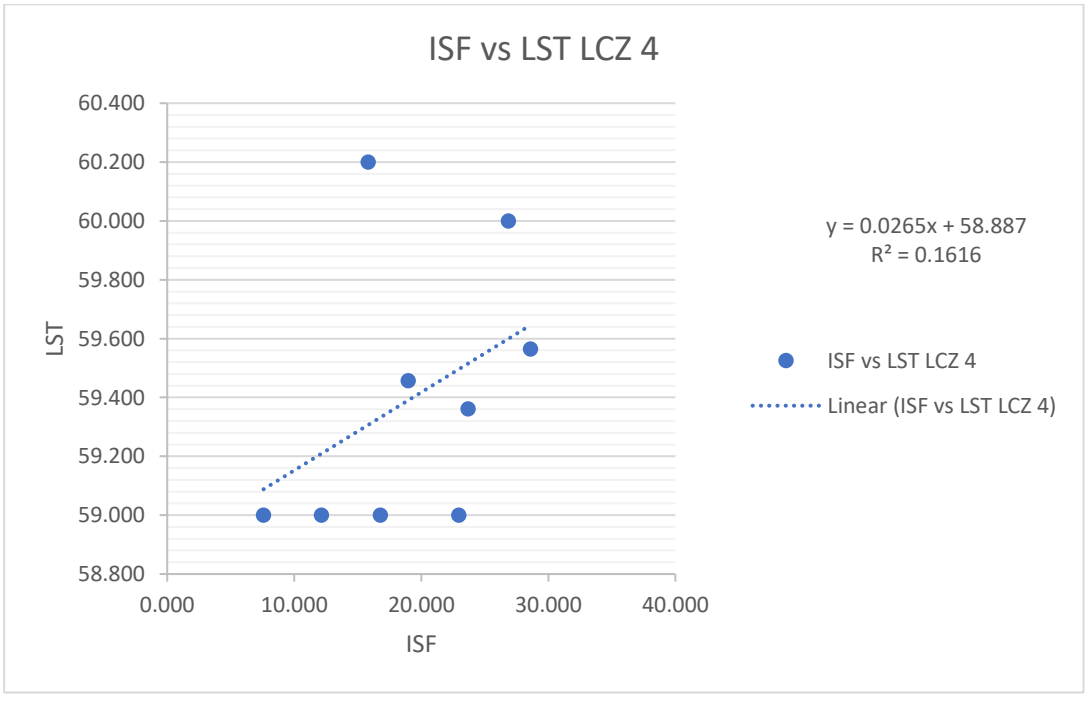


Figure 56 RelationbtwISFV/SLST *Source- Author*

This graph indicates a slight increase in temperature with higher impervious surfaces such as roads and paved areas. However, the relationship is relatively weak.

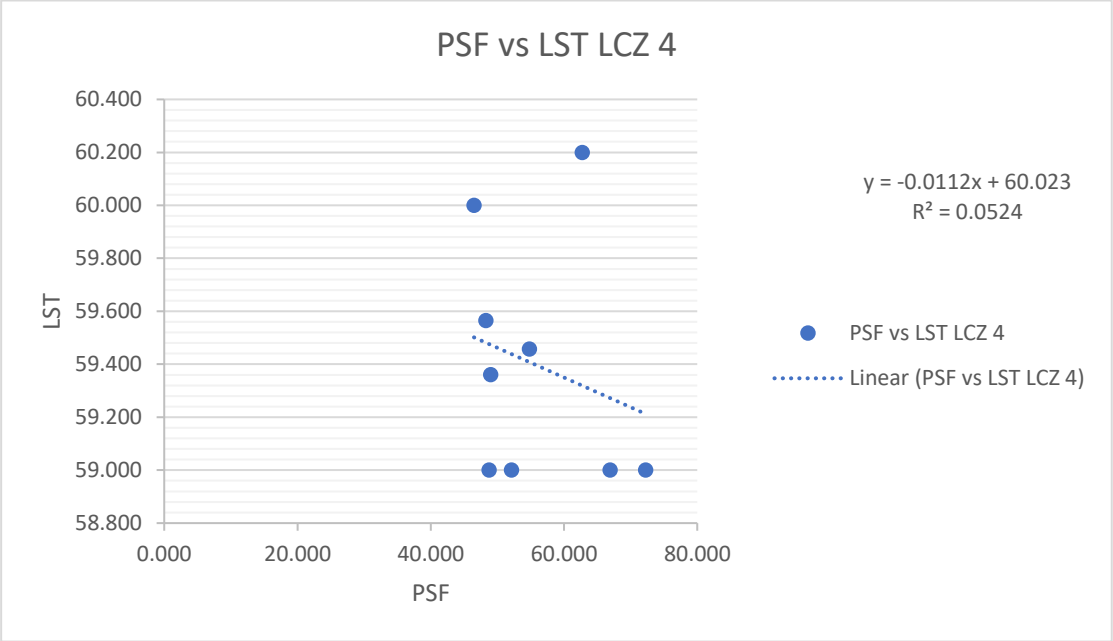


Figure 57 RelationbtwPSFV/SLST *Source- Author*

This graph shows very little relationship between pervious surfaces and surface temperature. Changes in water-absorbing surfaces do not significantly affect LST in this zone.

The graph illustrates the relationship between Pervious Surface Fraction (PSF) and Land Surface Temperature (LST) in LCZ 4 (Open High-Rise). The trendline shows a slight negative relationship ($y = -0.0112x + 60.023$), indicating that LST tends to decrease marginally as PSF increases. However, the R^2 value of 0.0524 is very low, suggesting that PSF has a very weak influence on LST in this LCZ. The data points are widely scattered, with temperatures ranging from approximately 59.0°C to 60.2°C across different PSF values. This indicates that factors other than PSF are likely playing a more significant role in determining surface temperature in LCZ 4.

4.11.5 LCZ V-Based Urban Thermal Pattern Analysis

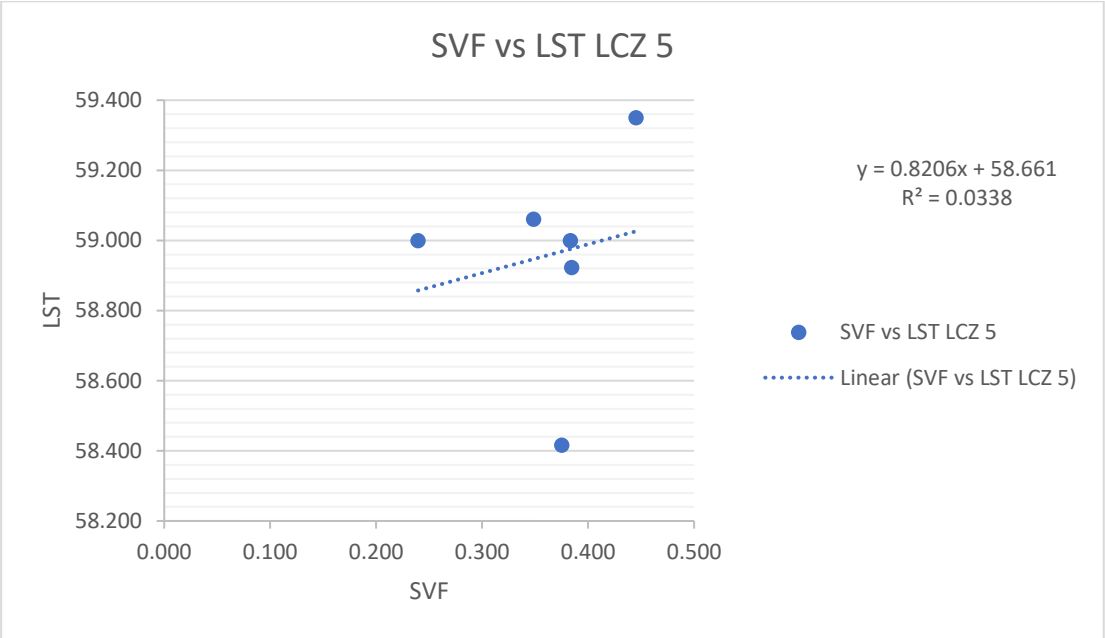


Figure 58 Relation btw SVFV/SLST *Source- Author*

This graph shows very little relationship between Sky View Factor (SVF) and surface temperature Sky visibility does not significantly affect temperature in LCZ 5.graph shows a very weak relationship between Sky View Factor (SVF) and Land Surface Temperature (LST) in LCZ 5. The scattered distribution of data points and the nearly flat trendline indicate that changes in sky visibility have minimal influence on surface temperature within this local climate zone. Although SVF is generally linked to urban openness, solar exposure, and airflow, the results suggest that it does not significantly control thermal conditions in LCZ 5. Areas with both high and low sky visibility exhibit relatively similar temperature values, showing limited variation in LST due to SVF alone. This weak relationship implies that other urban factors, such as building materials, impervious surfaces, vegetation cover, and urban density, may play a more dominant role in determining temperature patterns. The findings suggest that sky visibility is not a major controlling parameter of urban heat in the selected LCZ 5 environment.

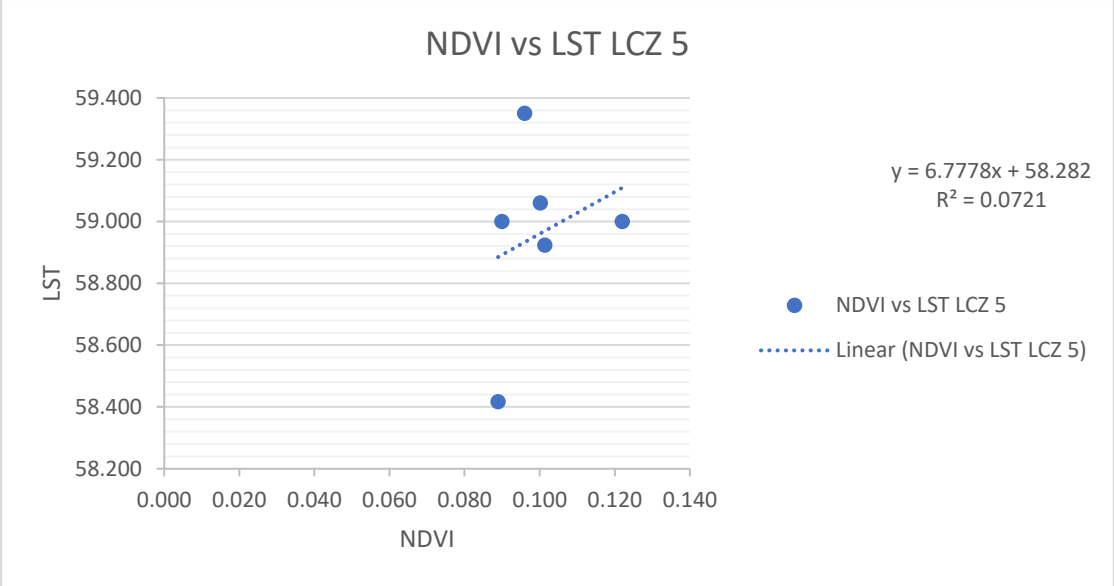


Figure 59 Relation btw NDVIV/SLST *Source- Author*

This graph shows a very weak relationship between vegetation and surface temperature. Greenery does not show a strong cooling effect in this zone.

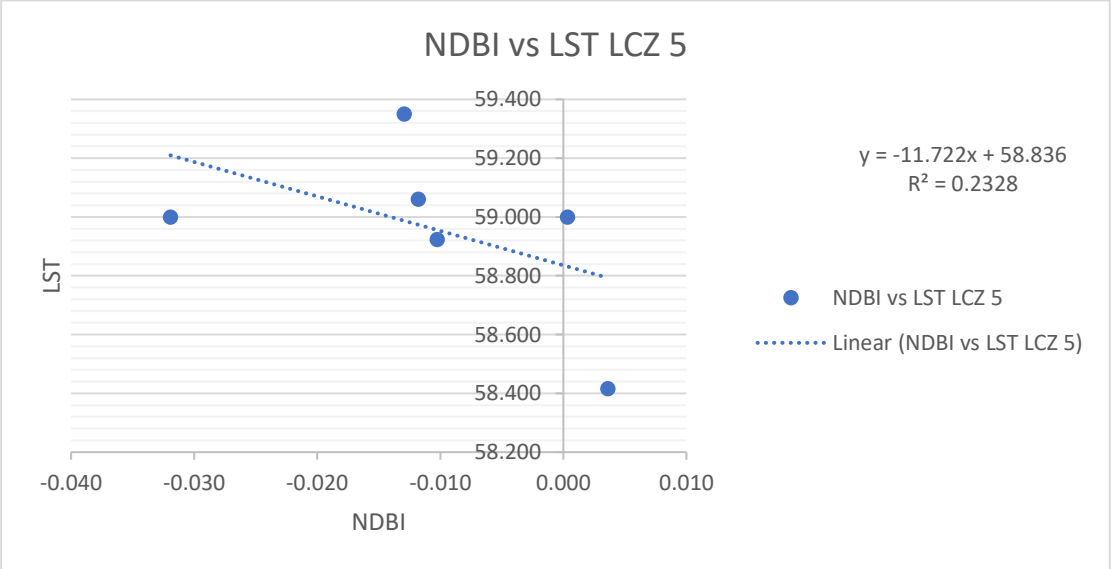


Figure 60 Relation btw NBDIV/SLST *Source- Author*

This graph indicates a slight decrease in temperature with increasing built-up density. However, the relationship is weak in this dataset.

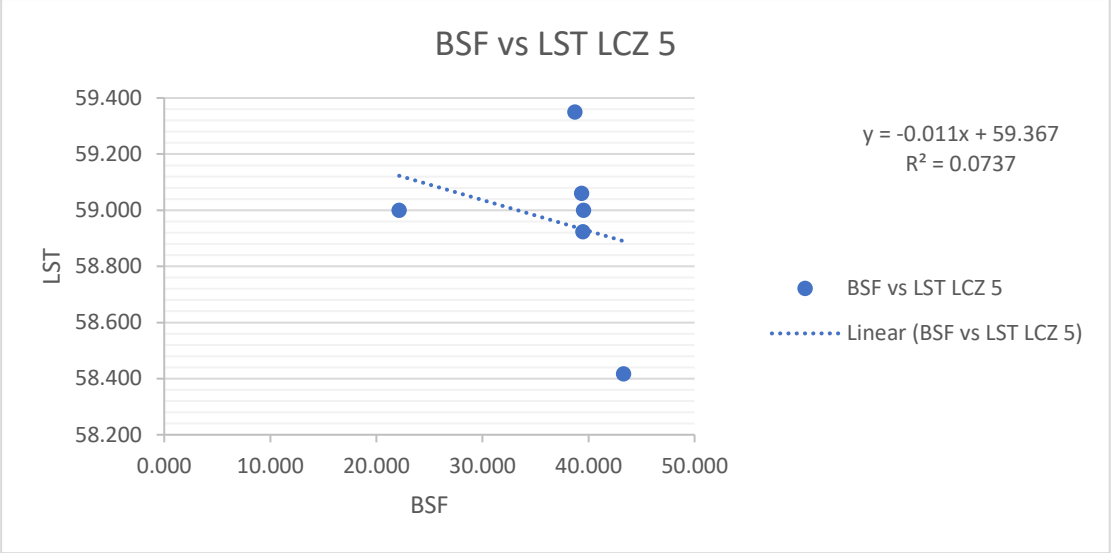


Figure 61 Relation btw BSF V/S LST *Source- Author*

This graph shows very little relationship between Building Surface Fraction (BSF) and surface temperature Building coverage does not significantly affect LST in LCZ 5.

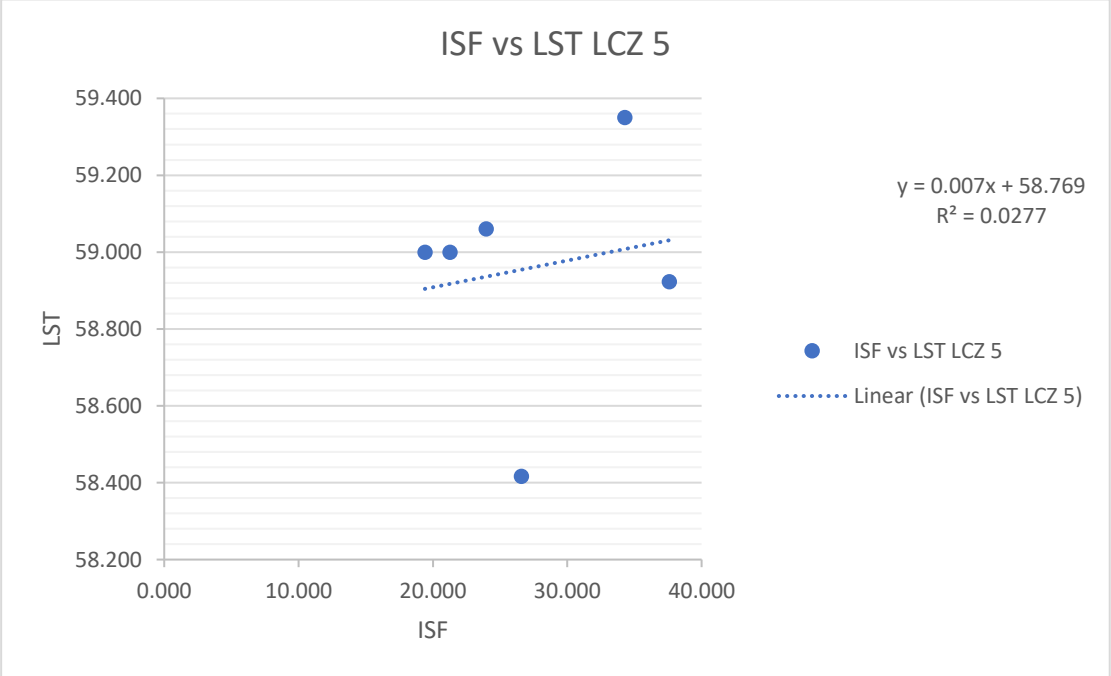


Figure 62 Relation btw ISF V/S LST *Source- Author*

This graph indicates that impervious surfaces such as roads and paved areas have very little effect on surface temperature in this zone.

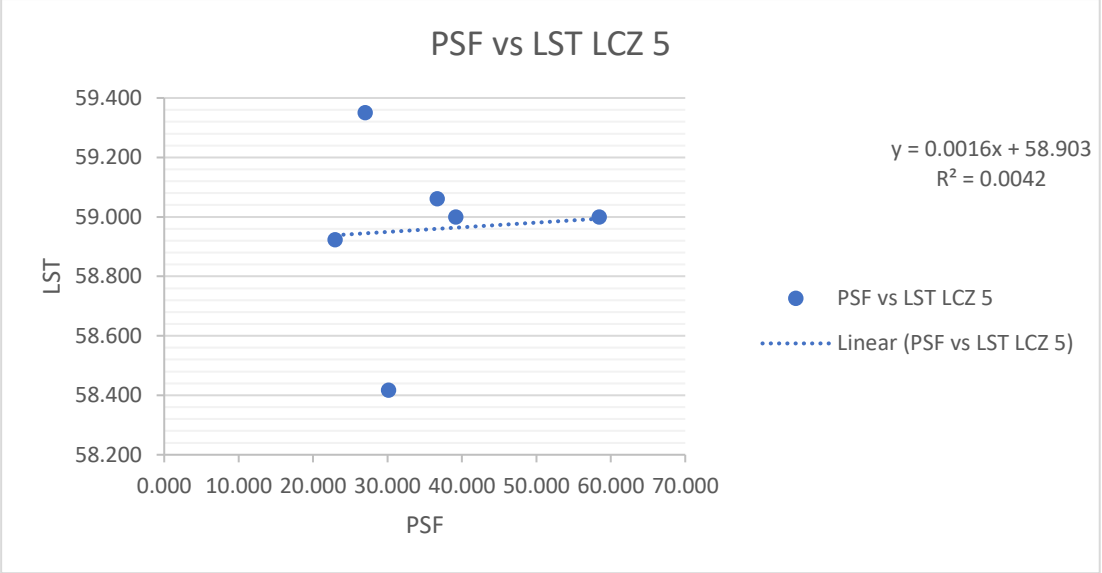


Figure 63 Relation btw PSF V/S LST *Source- Author*

This graph shows almost no relationship between pervious surfaces and surface temperature. Water-absorbing surfaces do not significantly influence LST in LCZ 5.

4.11.6 LCZ X-Based Urban Thermal Pattern Analysis

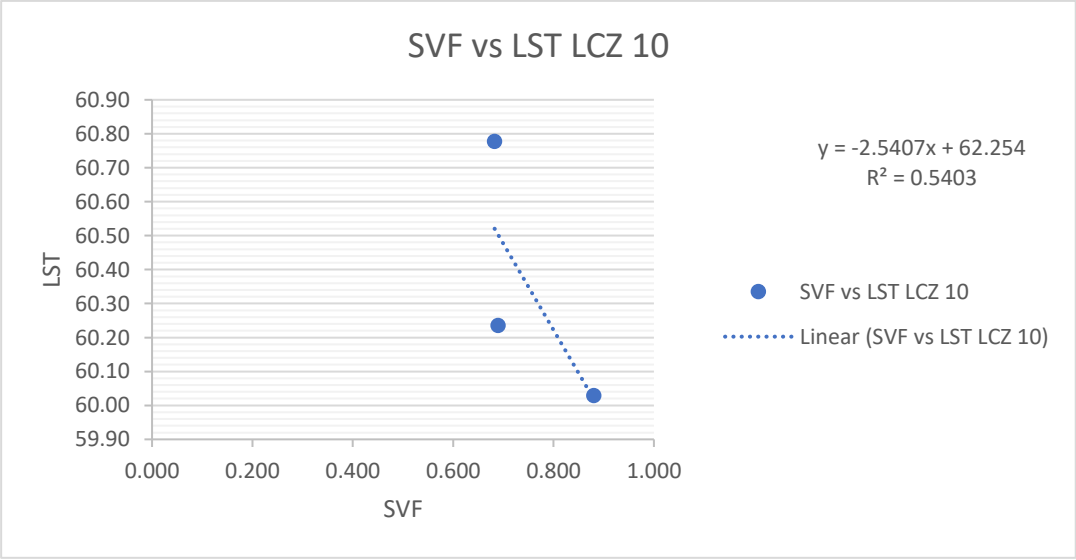


Figure 64 Relation btw SVF V/S LST *Source- Author*

The trendline indicates a negative relationship between SVF and LST. This means that when SVF increases, LST tends to decrease slightly. The R 2 0 5403 R^ 2 0 5403 R 2 0 5403 value shows a moderate relationship between SVF and LST, meaning SVF has a noticeable effect on surface temperature variation.

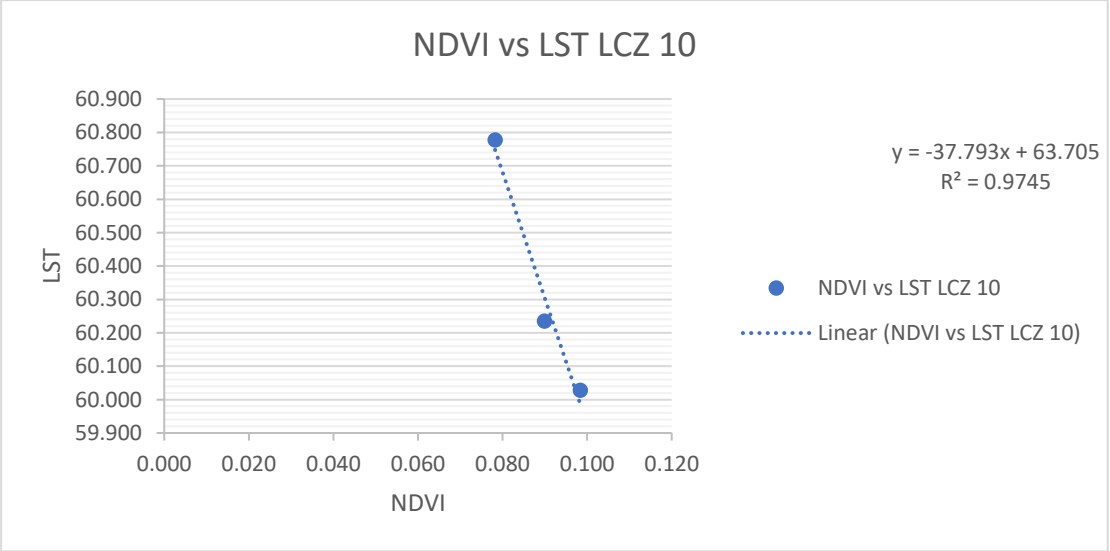


Figure 65 Relation btw NDVI V/S LST *Source- Author*

Strong negative correlation exists between NDVI and LST. Increase in vegetation cover significantly decreases surface temperature. Vegetation acts as an effective cooling element in industrial zones.

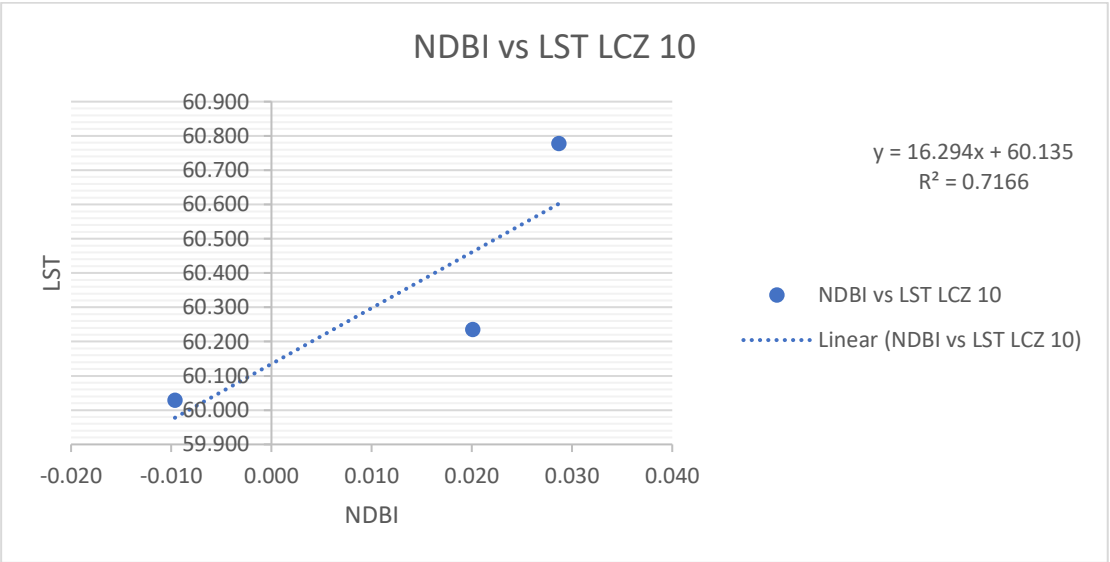


Figure 66 Relation btw NBDI V/S LST *Source- Author*

Higher built up intensity contributes to increased heat accumulation. Positive relationship is observed between NDBI and LST. Industrial infrastructure and impervious surfaces intensify thermal conditions.

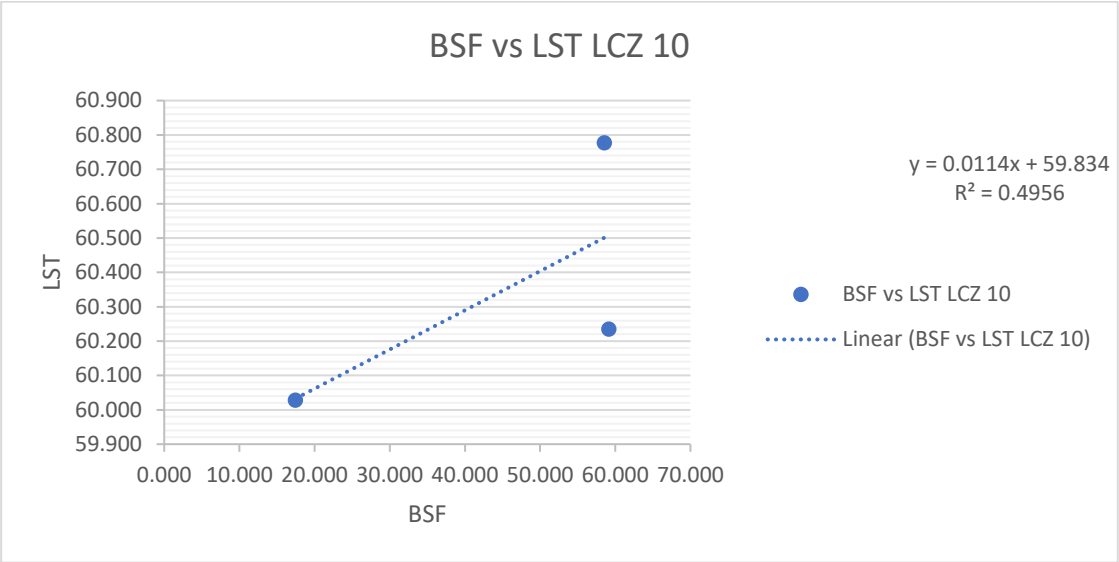


Figure 67 Relation btw BSF V/S LST *Source- Author*

BSF shows a positive correlation with LST. Higher building surface fraction increases heat retention and surface warming. Dense industrial structures contribute to elevated temperatures.

This graph indicates a moderate positive relationship between Building Surface Fraction (BSF) and Land Surface Temperature (LST) in LCZ 10 (Heavy Industry). The positive trendline ($y = 0.0114x + 59.834$) suggests that surface temperature tends to increase as building coverage increases. The R^2 value of 0.4956 indicates that nearly 50% of the variation in LST can be explained by changes in BSF, showing a moderate association between the two variables.

Areas with higher building density generally exhibit higher temperatures, likely due to the greater concentration of built-up surfaces that absorb and retain heat. This finding suggests that dense industrial structures may contribute to increased heat accumulation within LCZ 10. 9

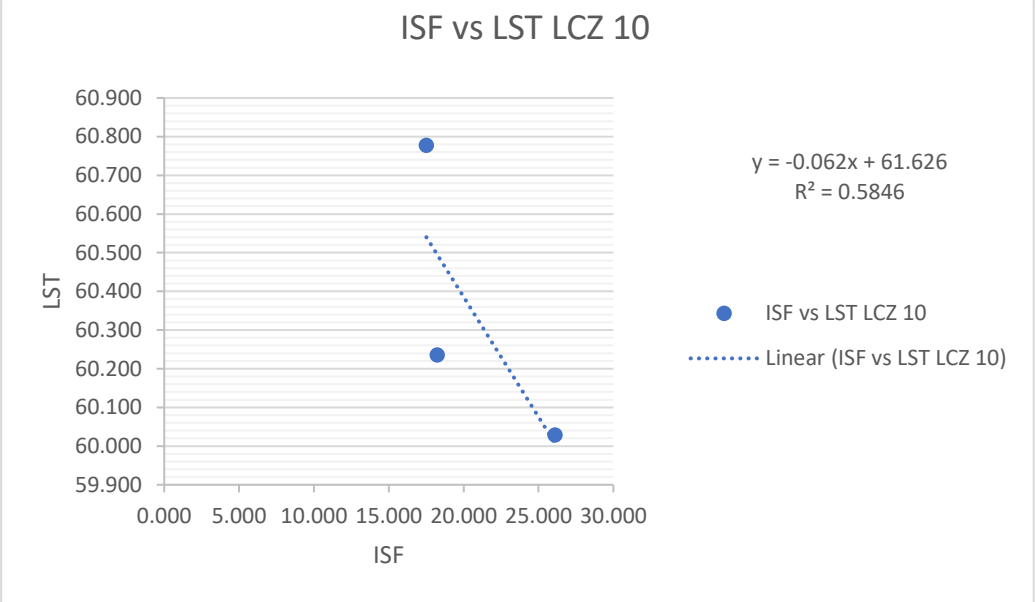


Figure 68 Relation btw ISF V/S LST *Source- Author*

Negative relationship is observed between ISF and LST. Increased impervious surface fraction in this dataset shows slight cooling variation, possibly due to reflective industrial surfaces or spatial heterogeneity. Moderate correlation suggests mixed thermal behaviour.

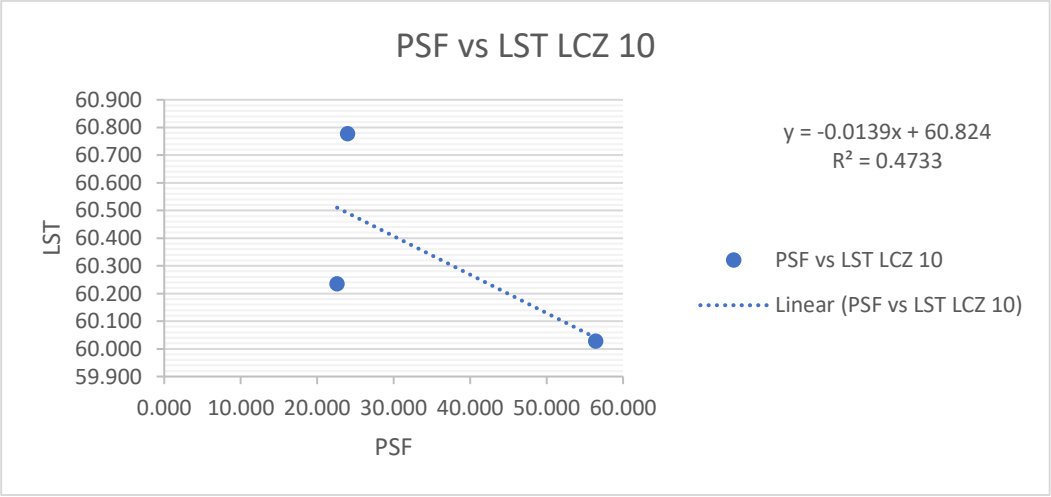


Figure 69 Relationbtw PSFV/SLST *Source- Author*

PSF demonstrates a negative correlation with LST. Increase in pervious surfaces helps reduce surface temperature through infiltration and reduced heat storage. Open and permeable surfaces contribute to thermal moderation.

Chapter- 5
Result & Discussion

5.1 Results and Discussion

The study evaluated the spatial variation of urban heat risk in Indore city using Local Climate Zone (LCZ) classification, Land Surface Temperature (LST) analysis, hotspot mapping, Sky View Factor (SVF), and urban morphology indicators. The findings clearly demonstrate that urban form plays a significant role in influencing thermal conditions and the intensity of the Urban Heat Island (UHI) effect.

The LST analysis revealed a substantial increase in surface temperature within densely built urban areas between 2015 and 2025. Core urban zones characterized by compact development patterns recorded the highest temperatures, while vegetated and open areas showed relatively lower thermal values. The hotspot analysis using Getis-Ord Gi* statistics identified statistically significant heat clusters concentrated mainly in highly urbanized and impervious areas of the city. These hotspot zones were largely associated with compact high-rise, compact midrise, compact low-rise, and industrial typologies.

The LCZ-based analysis indicated that LCZ 1, LCZ 2, and LCZ 3 exhibited comparatively higher Land Surface Temperatures due to dense built-up morphology, reduced vegetation cover, narrow street canyons, and limited airflow. Compact Midrise (LCZ 2) areas particularly demonstrated severe heat accumulation because of high building density, increased impervious surfaces, and low Sky View Factor values. Similarly, heavy industrial zones (LCZ 10) also recorded elevated temperatures due to large paved surfaces, industrial activities, and minimal green cover.

The relationship between urban morphology indicators and LST further highlighted the influence of built environment characteristics on urban thermal conditions. NDVI showed a negative correlation with LST, indicating that areas with higher vegetation cover experienced lower temperatures and improved thermal comfort. In contrast, NDBI and Impervious Surface Fraction (ISF) demonstrated a positive relationship with LST, confirming that built-up and paved surfaces significantly contribute to heat accumulation.

Sky View Factor (SVF) analysis suggested that areas with restricted sky exposure and compact urban canyons tend to trap heat and reduce ventilation efficiency, thereby intensifying local thermal stress. Building Surface Fraction (BSF) and impervious surface concentration also contributed to higher heat retention within compact urban neighbourhoods. These findings confirm that urban density, morphology, and surface characteristics strongly influence neighbourhood-level heat vulnerability.

The study also demonstrates that compact and highly urbanized typologies are more thermally vulnerable compared to open midrise and vegetated areas. Open urban forms with better ventilation, lower building density, and increased vegetation exhibited comparatively lower LST values and improved microclimatic conditions. This highlights the importance of integrating green infrastructure, reflective materials, and climate-responsive planning approaches within high-density urban areas.

Overall, the research establishes a strong relationship between urban morphology and heat risk in Indore city. The results emphasize that neighbourhood-scale spatial analysis is essential for identifying localized heat vulnerabilities and developing targeted mitigation strategies. The study contributes toward evidence-based urban planning practices aimed at reducing Urban Heat Island intensity, improving thermal comfort, and enhancing long-term urban resilience under changing climatic conditions.

5.2 Discussion

Cooling interventions under government-led pilot projects may include the implementation of extensive green roofs, cool reflective roofing systems, urban tree plantation, vertical gardens, shaded pedestrian spaces, and water-based cooling techniques in heat-vulnerable areas. These interventions are intended to reduce surface temperature, improve thermal comfort, and minimize localized Urban Heat Island (UHI) intensity within densely built urban environments.

Public infrastructure such as Indore Municipal Corporation (IMC) buildings, Indore Metro stations, AICTSL bus depots, government hospitals, educational institutions, and administrative campuses can be identified as priority locations for pilot implementation. Since these public facilities experience high pedestrian movement and prolonged heat exposure, integrating climate-responsive cooling measures can significantly improve user comfort during extreme summer conditions.

Interventions may include:

1. Installation of extensive green roofs and reflective cool roofs to reduce roof heat absorption
2. Development of shaded green canopies and tree-lined pedestrian pathways
3. Integration of vertical greenery systems on building facades and transit infrastructure
4. Use of permeable paving materials and landscape buffers around public spaces

Installation of automated sprinkler and water misting systems at bus stops, metro stations, and public plazas located within identified heat hotspot zones

Water-based cooling systems, particularly misting and sprinkler systems, can help reduce ambient temperature in highly exposed transit-oriented spaces where thermal discomfort remains significantly high during peak summer periods. These systems, when combined with vegetation and shaded structures, can improve microclimatic conditions and enhance pedestrian comfort. The strategy also supports the creation of urban cooling corridors along major transportation routes and public movement networks. Continuous vegetation belts, shaded walkways, and green buffers around transit infrastructure can improve airflow, reduce heat retention, and strengthen neighbourhood-level climate resilience.

Based on the spatial and morphological analysis, the study proposes several heat-resilient planning strategies including green roofs, cool roofs, increased urban vegetation, permeable surfaces, shaded pedestrian corridors, and improved ventilation pathways. The findings support the integration of heat mitigation measures into Development Control Regulations (DCR) and urban planning policies to promote climate-responsive and thermally resilient urban development.

Particular emphasis can be given to bus stops, metro station plazas, public waiting areas, and major pedestrian movement corridors located within identified urban heat hotspot zones. These spaces may incorporate automated sprinkler and fine misting systems integrated with shaded green canopies, tensile structures, and vegetated buffers to provide immediate microclimatic cooling during peak summer periods. The combined use of vegetation and evaporative cooling techniques can significantly lower localized ambient temperature, reduce thermal discomfort, and improve pedestrian experience within high-density urban settings.

Chapter - 6
Proposal and Outcome

6.1 Strategy 1: Policy Formulation and Regulatory Integration

A strong policy and regulatory framework is essential for the successful implementation of heat-resilient urban development strategies. Voluntary adoption of cooling measures is often limited; therefore, integration within existing planning regulations and building by-laws is necessary. This strategy proposes amendments to the Madhya Pradesh Bhumi Vikas Niyam and the Development Control Regulations (DCR) of Indore to incorporate mandatory heat-mitigation measures in urban development practices.

The proposed regulation may require a minimum 20–30% coverage of extensive green roofs or other heat-resilient roof treatments for commercial plots larger than 1000 sq.m, high-rise buildings, institutional developments, and large public infrastructure projects. Compliance with these provisions can be linked to the approval process and issuance of the final Occupancy Certificate (OC). Such regulatory integration would ensure that thermal comfort and climate-responsive design become an essential part of urban development rather than optional interventions.

This strategy is inspired by the *Telangana Cool Roof Policy (2023–2028)* introduced by the Municipal Administration & Urban Development Department, Government of Telangana, which mandates the use of cool and reflective roofing materials for non-residential buildings and large residential plots (Government of Telangana, 2023).

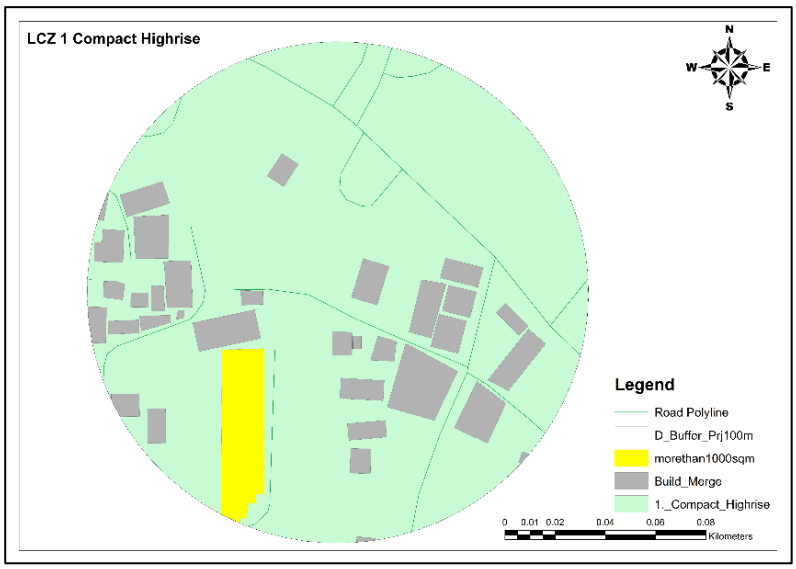


Figure 70 LCZ 1 Compact high-rise typologies *source author*

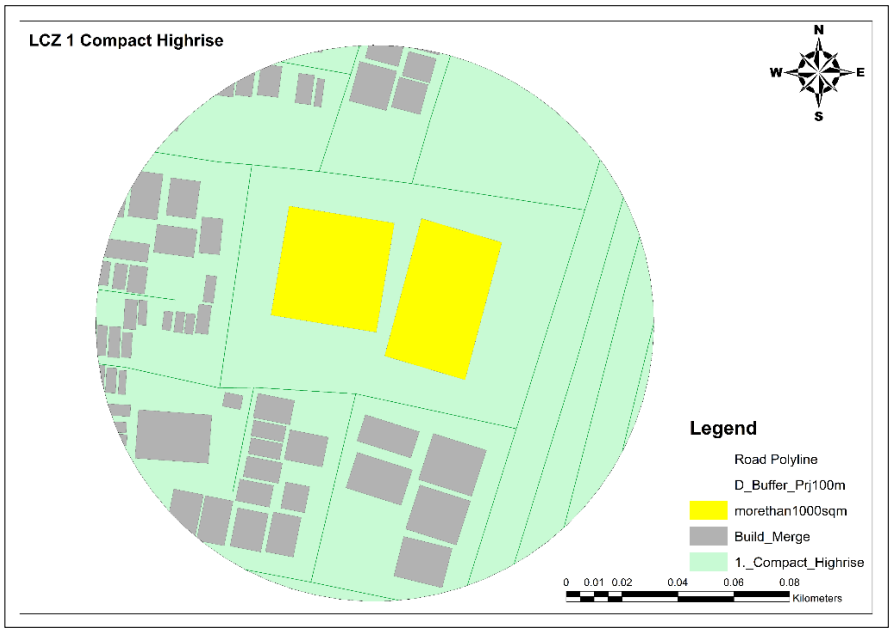


Figure 71 LCZ1 Compact high-rise typologies *source author*

6.2 Strategy 2: Government-Led Demonstration and Pilot Projects

Government-led pilot projects play an important role in demonstrating the practical feasibility, effectiveness, and maintenance requirements of heat-resilient infrastructure before large-scale implementation. Public sector initiatives can encourage confidence among private developers, institutions, and citizens by showcasing successful examples of climate-responsive urban design.

Under this strategy, extensive green roofs and other cooling interventions can be implemented on selected public buildings and infrastructure projects such as Indore Municipal Corporation (IMC) buildings, Indore Metro stations, AICTSL bus depots, government hospitals like MY Hospital, educational institutions, and administrative offices. These pilot projects can serve as demonstration models for evaluating thermal performance, structural safety, energy savings, and maintenance requirements under local climatic conditions. Similar government-led demonstration approaches have also been emphasized under the *Telangana Cool Roof Policy (2023–2028)* for promoting climate-responsive urban infrastructure and sustainable heat mitigation practices (Government of Telangana, 2023).Indian Base Reference: Ahmedabad Heat Action Plan (HAP) by the AMC.How it worked: When Ahmedabad launched its pioneering Heat Action Plan to combat the Urban Heat Island (UHI) effect, the Ahmedabad Municipal Corporation (AMC) did not start with private buildings..

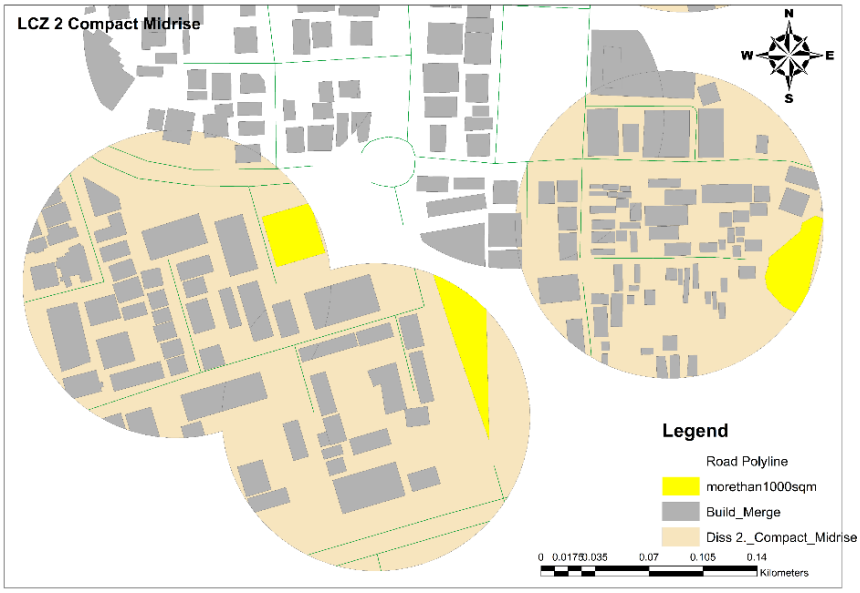


Figure 72 LCZ 2Compact midrise typologies *source author*

Tiered property tax rebate system can be introduced to encourage the adoption and maintenance of green roofs in urban areas. Under this strategy, building owners who install and maintain green roofs would receive a reduction of 5% to 15% on their annual property tax, depending on the extent and performance of the green infrastructure. This proposal is based on the successful implementation of property tax incentives by Pune Municipal Corporation (PMC), where buildings complying with eco-housing and green building standards are granted tax rebates ranging from 5% to 15%. Similarly, Pimpri-Chinchwad Municipal Corporation (PCMC) has provided financial incentives to promote green building practices. Adopting a comparable incentive mechanism can encourage sustainable building design, increase urban green cover, reduce heat stress, and contribute to the development of heat-resilient cities.

6.3 Strategy 3: Policy Mandate and Building Code Integration for Cool Roofs

To ensure the long-term adoption of cool roofs in Indore, cool roof standards should be formally integrated into the city's Development Control Regulations (DCR) and building approval process. Instead of treating cool roofs as optional measures, they should become a mandatory component of future urban development and affordable housing projects.

6.3.1 Proposed Action

The Indore Development Authority (IDA) and Municipal Corporation can introduce regulations requiring all new government buildings, commercial complexes,

institutional buildings, and PMAY (Pradhan Mantri Awas Yojana) housing projects to adopt cool roofing materials with a minimum Solar Reflectance Index (SRI) greater than 70. Building proposals that do not comply with the prescribed cool roof standards may not receive construction approval.

This policy can include:

- Mandatory use of high-reflective roof coatings or tiles
- Use of light-colored roofing materials
- Inclusion of cool roof specifications in building bye-laws
- Incentives or fast-track approvals for compliant buildings
- Integration with green building and climate-resilient planning guidelines

Expected Benefits

- Reduction in roof surface temperatures and indoor heat gain
- Lower cooling energy demand and electricity consumption
- Improved thermal comfort, especially in low-income housing

6.4 Strategy 3: Policy Mandate for Cool Roofs

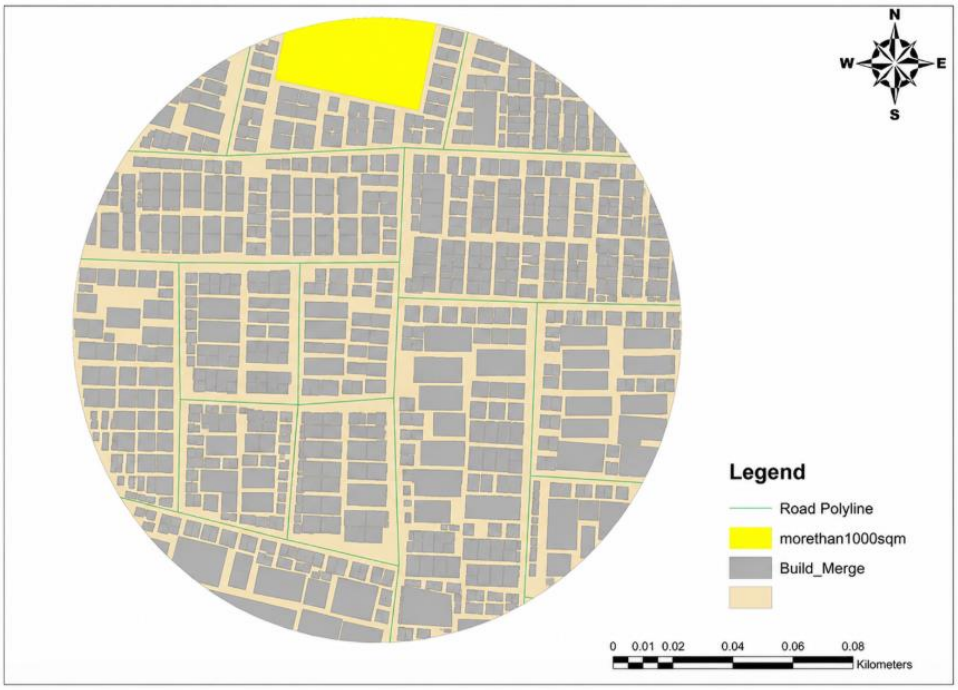


Figure 73 LCZ 7 light weight low rise typologies *source author*

Proposed Amendments for LCZ 7 – Lightweight Low rise

I. Slum and Low-Income High Heat Risk Areas

II. Urban Greening Strategies

III. Increase roadside plantation and shaded community spaces within dense settlements

IV. Develop pocket parks and small neighborhood green areas in vacant land parcels

V. Promote vertical gardens and low-maintenance vegetation near public spaces and pathways

VI. Create green buffers along drainage channels, roads, and railway edges

VII. Cool Surface Strategies

VIII. Implement cool roof coatings and reflective white paint on tin, asbestos, and concrete roofs

IX. Promote low-cost high-albedo roofing materials through government support schemes

X. Replace concrete paving with permeable and heat-resistant surface materials

XI. Introduce shaded roofing sheets and solar-reflective coverings in vulnerable housing clusters

XII. Government should provide subsidies for cool roofs, reflective paints, and heat-resistant construction materials in low-income housing areas

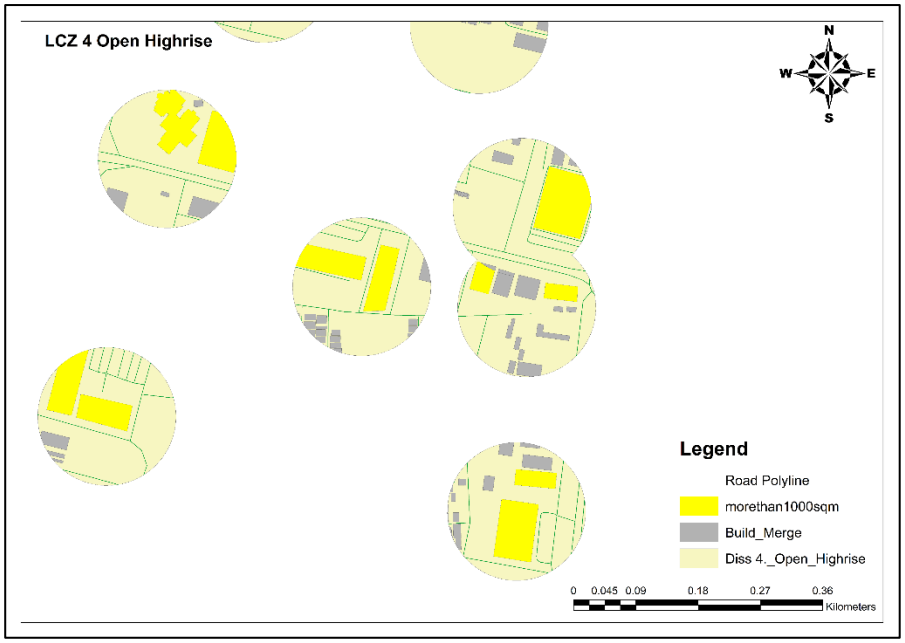


Figure 74 LCZ 4 open high-rise typologies *source author*

Open high-rise areas experience high solar exposure due to large open spaces and limited greenery. Heat often gets trapped between tall buildings, while concrete and reflective surfaces further increase surrounding temperatures. To reduce heat stress, strategies such as increasing tree plantation, developing pocket parks and green buffers, using cool roofing materials, introducing vertical greening, and creating shaded pedestrian pathways can help improve thermal comfort and reduce the Urban Heat Island (UHI) effect.

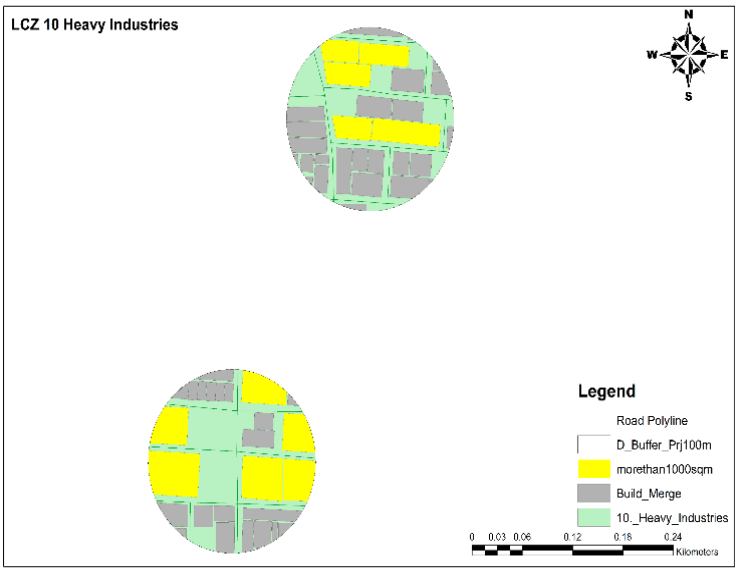


Figure 75 15 LCZ 10 heavy industry *source author*

Suggested Strategies

I. Increase tree plantation around towers and roads

II. Develop green buffers and pocket parks

III. Use cool roofs and reflective building materials

IV. Introduce vertical greening on building facades

6.5 Existing Environmental and Thermal Conditions Analysis

The proposed Startup Park on the Super Corridor in Indore is envisioned as a landmark business and innovation hub that will promote entrepreneurship, technology, and economic growth in the city. Planned over an area of 8.2 hectares under Scheme No. 151 and 169-B, the project comprises high-rise commercial towers with modern infrastructure designed to attract startups, IT companies, and business enterprises. With an estimated investment of ₹700 crore, the development is expected to accommodate nearly 100 startups and technology firms, generating significant employment opportunities and strengthening Indore's position as an emerging innovation center.

The project incorporates a range of facilities, including startup offices, co-working spaces, incubation centers, retail and commercial spaces, a five-star hotel, restaurants, an auditorium, entertainment zones, and training centers. Sustainable features such as green building concepts, solar energy systems, and EV charging infrastructure have also been proposed to support environmentally responsible development. Strategically located along the rapidly developing Super Corridor, the Startup Park is expected to become a major economic catalyst, attracting investment, fostering innovation, and contributing to the overall urban and economic development of Indore.



Figure 76 Start-up Park, Scheme No. 151 & 169-B, Super Corridor, source :- Indore Development Authority.

Startup Park –Introduction

Startup Park is a proposed high-rise mixed-use development project located at **Super Corridor**. The project is planned to promote startups, business activities, commercial growth, and employment opportunities. It will include offices, co-working spaces, exhibition centers, hotels, restaurants, shopping areas, entertainment zones, and other facilities.

Project Area: 8.2 Hectares
Building Height: 90 meters (26 floors)
Frontage: 560 meters
Estimated Cost: ₹700 Crore

The NDVI map represents the distribution of vegetation cover within the study area and its surrounding 500 m buffer zone. The NDVI values range from approximately -0.003 to 0.424, indicating varying levels of vegetation density. Higher NDVI values (0.28–0.42), shown in green shades, represent areas with relatively healthy and dense vegetation, while lower values (0.00–0.14), shown in orange and red shades, indicate built-up surfaces, barren land, or areas with sparse vegetation cover.

The study area predominantly falls within the 0.14–0.28 NDVI range, suggesting moderate vegetation presence. However, several surrounding areas exhibit low NDVI values, reflecting a dominance of impervious surfaces and limited green cover. Pockets of higher NDVI values are mainly concentrated in the western and south-western portions of the buffer area, where vegetation contributes to a cooler microclimate and improved environmental conditions.

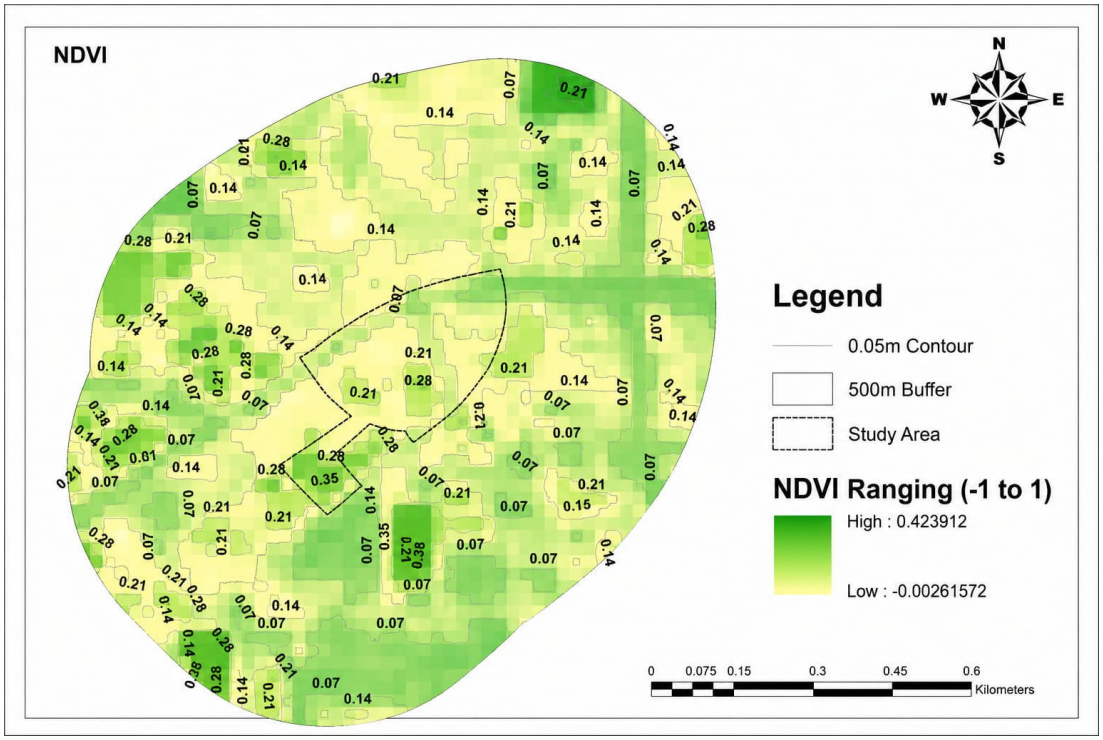


Figure 77 NDVI Analysis *source :-Author*

The spatial pattern indicates that vegetation cover is unevenly distributed across the study area. Areas with lower NDVI values are likely to experience higher land surface temperatures, while areas with higher NDVI values may help mitigate heat stress through shading and evapotranspiration. Therefore, increasing vegetation cover through green infrastructure, urban landscaping, and tree plantation initiatives can play a significant role in reducing heat risk and enhancing thermal comfort within the proposed development.

Normalized Difference Built-up Index (NDBI) map illustrates the spatial distribution of built-up and non-built-up surfaces within the study area and its 500 m buffer. The NDBI values range from approximately **-0.277 to 0.099**, where positive values indicate

built-up surfaces such as buildings, roads, and paved areas, while negative values represent vegetation, open spaces, and other non-urban land covers.

The study area predominantly exhibits NDBI values close to 0 and 0.05, indicating a moderate presence of built-up surfaces and urban development. Higher NDBI values are observed in scattered pockets across the buffer zone, representing areas with greater concentrations of impervious surfaces and urban infrastructure. In contrast, the western and south-western portions show lower and negative NDBI values, corresponding to vegetation-covered or open land areas.

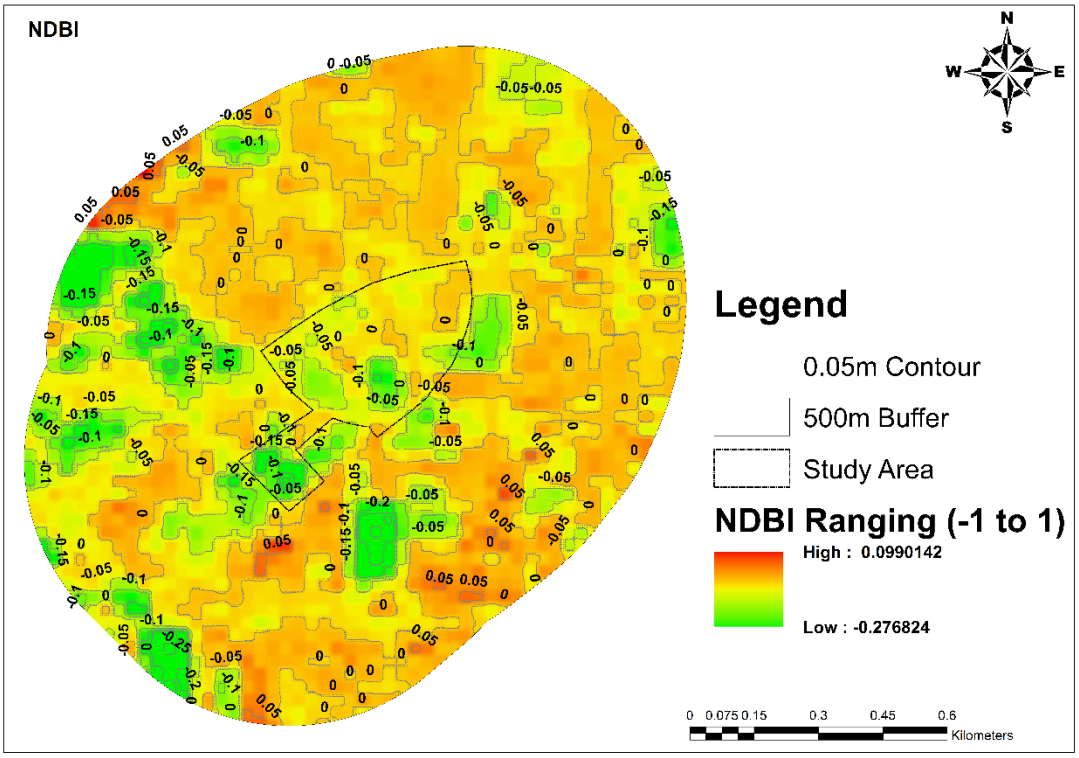


Figure 78 NDBI Analysis *source : Author*

The spatial pattern suggests a mixed urban landscape where built-up surfaces are interspersed with patches of vegetation. Areas with relatively higher NDBI values are more likely to experience elevated land surface temperatures due to the heat-retaining characteristics of impervious materials. Therefore, controlling excessive built-up density and integrating green infrastructure within future developments can help mitigate urban heat accumulation and improve the thermal environment of the study area.

land Surface Temperature (LST) Analysis

The Land Surface Temperature (LST) map indicates a temperature range of approximately 58°C to 63°C within the 500 m buffer area surrounding the study site. The highest temperatures are observed in the southern and south-eastern portions of the buffer zone, where LST values reach 62–63°C, representing potential heat hotspots. These areas are likely associated with extensive impervious surfaces, sparse vegetation cover, and exposed built-up land.

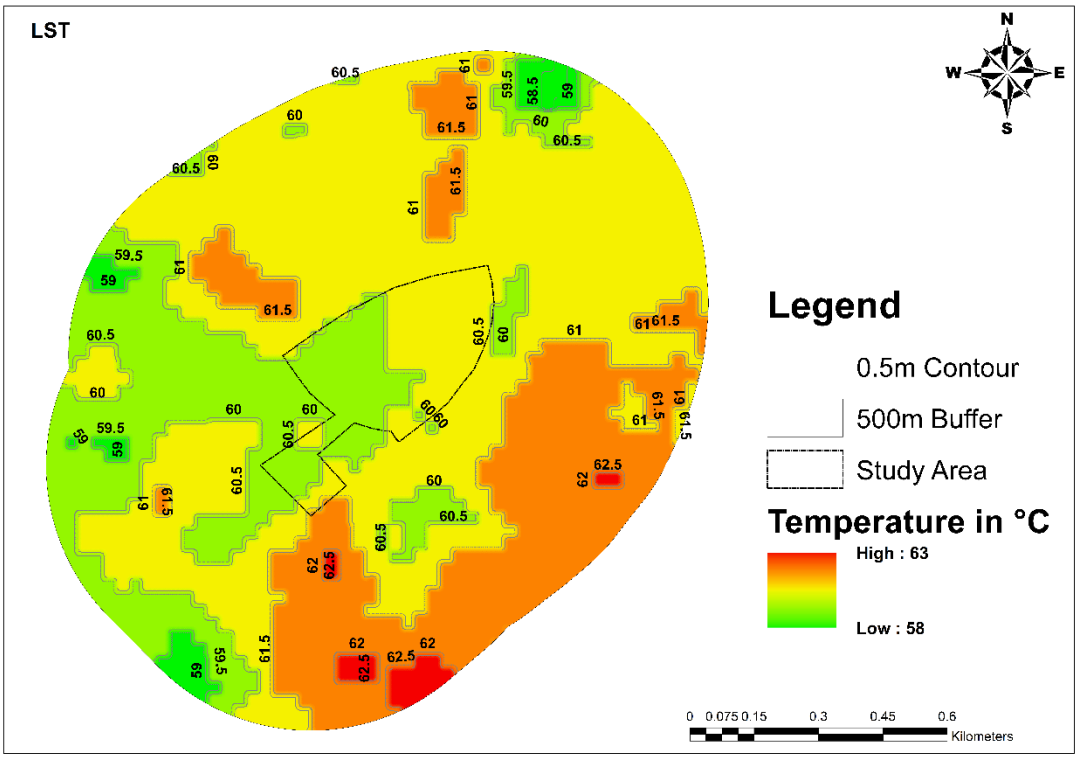


Figure 79 Ist Analysis *source : Author*

In contrast, the western and north-western regions exhibit relatively lower temperatures ranging from 58°C to 60°C, suggesting the presence of vegetation, open spaces, or other cooling elements that help moderate surface temperatures. The study area itself falls predominantly within the 60–61°C temperature zone, indicating a moderate thermal environment compared to the surrounding hotspot areas.

The spatial distribution of LST highlights a clear variation in surface temperature across the buffer area and demonstrates the influence of land cover characteristics on urban

heat conditions. The proximity of high-temperature zones to the study area emphasizes the need for heat-mitigation measures such as increased vegetation cover, shaded public spaces, cool mate

The analysis reveals that areas with higher built-up intensity and lower vegetation cover generally correspond to higher surface temperatures, whereas vegetated areas exhibit relatively cooler conditions. This highlights the importance of integrating green infrastructure and climate-responsive planning measures to reduce heat stress within the proposed development area.

proposed intervention for the Super Corridor focuses on reducing urban heat risk through climate-responsive planning and sustainable urban design. The Land Surface Temperature (LST) analysis identified several high-temperature hotspots within and around the study area, with temperatures ranging between **61.5°C and 63°C**, primarily due to extensive built-up surfaces, limited vegetation, and a high proportion of impervious areas. To address these challenges, the proposal recommends increasing green infrastructure through roadside plantations, linear parks, urban forests, and pocket parks to enhance shading and evapotranspiration. The use of cool roofs, reflective building materials, and permeable pavements is proposed to minimize heat absorption and improve surface cooling. shaded pedestrian walkways, dedicated cycling tracks, and landscaped public spaces are incorporated to enhance outdoor thermal comfort and encourage sustainable mobility. Rainwater harvesting systems and bioswales are also recommended to improve stormwater management while supporting urban cooling. Collectively, these interventions aim to reduce surface temperatures, improve the microclimate, strengthen urban resilience, and promote sustainable development within the Super Corridor

REFERENCES

1. Abedrabboh, Omer, M. Rami Alfarra, Tareq Al-Ansari, and Christos Fountoukis. 2025. "Enhancing Human Thermal Comfort in Hot Arid Cities: A Systematic Review of Urban Heat Island Observations and Mitigation Strategies." *Building and Environment* 283 (February): 113398. https://doi.org/10.1016/j.buildenv.2025.113398.

2. Akbari, Fazal Akbar, and Ayyoob Sharifi. 2024. "Examining the Suitability of the Local Climate Zones (LCZ) Framework in Informal Urban Settlements: Insights from Kabul, Afghanistan." *Sustainable Cities and Society* 114 (September): 105797. https://doi.org/10.1016/j.scs.2024.105797.

3. Hu, Haisheng. 2025. "Climate and Environmental Dynamics: Deciphering the Distribution and Vulnerability of World Heritage Sites in Europe." *Journal of Environmental Management* 392 (July): 126693. https://doi.org/10.1016/j.jenvman.2025.126693.

4. Ishak, Norishahaini Mohamed, Ansar Khan, Jamalunlaili Abdullah, Siti Aekbal Salleh, and Mattheos Santamouris. 2025. "Optimizing Seasonal Performance of Advanced Heat Mitigation Solutions for City-Scale Thermal Management in Greater Kuala Lumpur." *City and Environment Interactions* 28 (February): 100219. https://doi.org/10.1016/j.cacint.2025.100219.

5. Li, Xuetong, and Zhonghua Gou. 2025. "Urban Morphology and Energy Self-Sufficiency: A Comparative Study of Residential Blocks in Eight Global Cities." *Cities* 166 (July): 106240. https://doi.org/10.1016/j.cities.2025.106240.

6. Schöneberger, Peer, Tim Sinsel, Wanlu Ouyang, Zheng Tan, Michael Bruse, and Helge Simon. 2025. "Enhancing Urban Microclimate Simulations: Validating ENVI-Met's Accuracy in Modeling Multi-Directional Radiative Fluxes and Mean Radiant Temperature in Subtropical Hong Kong." *Building and Environment* 284 (July). https://doi.org/10.1016/j.buildenv.2025.113475.

7. Wang, Minghao, Yichen Dong, Wei Liao, Bo Pan, Sensheng Li, Junchao Duan, and Shen Xu. 2025. "Impact of Residential Morphology on Outdoor Thermal Comfort and

Building Energy Consumption in Winter and Summer: A Case Study." *Urban Climate* 61 (March): 102479. https://doi.org/10.1016/j.uclim.2025.102479.

8. Government of India, Ministry of Environment & Forests. (2008). *National Action Plan on Climate Change.*

9. Pandve, H. T. (2009). India's National Action Plan on Climate Change. *Indian Journal of Occupational and Environmental Medicine,* 13(1), 17–19.

10. NDMA. (2019). *National Guidelines for Preparation of Action Plan – Prevention & Management of Heat Wave.*

11. Ministry of Housing & Urban Affairs. (202x). *AMRUT 2.0 Operational Guidelines.*

12. Ministry of Urban Affairs. (202x). *Smart Cities Mission: Project Report / Achievements.*

13. Ministry of Environment, Forest & Climate Change. (2019). *India Cooling Action Plan.*

14. Schöneberger, P., Sinsel, T., Ouyang, W., Tan, Z., Bruse, M., & Simon, H. (2025). Enhancing urban microclimate simulations: Validating ENVI-met's accuracy in modeling multi-directional radiative fluxes and mean radiant temperature in subtropical hong kong. Building and Environment, 284(July). https://doi.org/10.1016/j.buildenv.2025.113475

15. Sharmin, T., & Chappell, A. (2025). Detecting the changing impact of urbanisation on urban heat islands in a tropical megacity using local climate zones. Energy and Built Environment, February. https://doi.org/10.1016/j.enbenv.2025.02.002

16. Sheng, X., Fei, G., PeiSheng, Z., ShiYu, M., WeiSi, L., Jun, Z., Xinyu, X., HongChi, Z., & Jing, D. (2025). Thermal environment disparities and adaptive mechanisms in wintertime cold coastal cities: An empirical study based on Local Climate Zones. Sustainable Cities and Society, 130(July), 106605. https://doi.org/10.1016/j.scs.2025.106605

17. Song, D., & Lu, M. (2025). The impact of high-density urban spatial form on urban vertical ventilation and thermal comfort in extreme cold region. Sustainable Cities and Society, 127(May), 106451. https://doi.org/10.1016/j.scs.2025.106451

18. Wang, D., Song, M., Chen, S., & Du, H. (2025). The impact of the global 100 resilient cities strategy on urban resilience under climate change. Cities, 167(August), 106370. https://doi.org/10.1016/j.cities.2025.106370

19. Wang, M., Dong, Y., Liao, W., Pan, B., Li, S., Duan, J., & Xu, S. (2025). Impact of residential morphology on outdoor thermal comfort and building energy consumption in winter and summer: A case study. Urban Climate, 61(March), 102479. https://doi.org/10.1016/j.uclim.2025.102479

20. Schöneberger, P., Sinsel, T., Ouyang, W., Tan, Z., Bruse, M., & Simon, H. (2025). Enhancing urban microclimate simulations: Validating ENVI-met's accuracy in modeling multi-directional radiative fluxes and mean radiant temperature in subtropical hong kong. Building and Environment, 284(July). https://doi.org/10.1016/j.buildenv.2025.113475

21. Sharmin, T., & Chappell, A. (2025). Detecting the changing impact of urbanisation on urban heat islands in a tropical megacity using local climate zones. Energy and Built Environment, February. https://doi.org/10.1016/j.enbenv.2025.02.002

22. Sheng, X., Fei, G., PeiSheng, Z., ShiYu, M., WeiSi, L., Jun, Z., Xinyu, X., HongChi, Z., & Jing, D. (2025). Thermal environment disparities and adaptive mechanisms in wintertime cold coastal cities: An empirical study based on Local Climate Zones. Sustainable Cities and Society, 130(July), 106605. https://doi.org/10.1016/j.scs.2025.106605

23. Song, D., & Lu, M. (2025). The impact of high-density urban spatial form on urban vertical ventilation and thermal comfort in extreme cold region. Sustainable Cities and Society, 127(May), 106451. https://doi.org/10.1016/j.scs.2025.106451

24. Wang, D., Song, M., Chen, S., & Du, H. (2025). The impact of the global 100 resilient cities strategy on urban resilience under climate change. Cities, 167(August), 106370. https://doi.org/10.1016/j.cities.2025.106370

25. Wang, M., Dong, Y., Liao, W., Pan, B., Li, S., Duan, J., & Xu, S. (2025). Impact of residential morphology on outdoor thermal comfort and building energy consumption in winter and summer: A case study. Urban Climate, 61(March), 102479. https://doi.org/10.1016/j.uclim.2025.102479

26. Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landscape and Urban Planning, 97*(3), 147–155. https://doi.org/10.1016/j.landurbplan.2010.05.006

27. Gill, S. E., Handley, J. F., Ennos, A. R., & Pauleit, S. (2007). Adapting cities for climate change: The role of the green infrastructure. *Built Environment, 33*(1), 115–133. https://doi.org/10.2148/benv.33.1.115

28. Getter, K. L., & Rowe, D. B. (2006). The role of extensive green roofs in sustainable development. *HortScience, 41*(5), 1276–1285. https://doi.org/10.21273/HORTSCI.41.5.1276

29. Kleerekoper, L., van Esch, M., & Salcedo, T. B. (2012). How to make a city climate-proof, addressing the urban heat island effect. *Resources, Conservation and Recycling, 64*, 30–38. https://doi.org/10.1016/j.resconrec.2011.06.004

30. Oke, T. R. (1982). The energetic basis of the urban heat island. *Quarterly Journal of the Royal Meteorological Society, 108*(455), 1–24. https://doi.org/10.1002/qj.49710845502

31. Pauleit, S., Liu, L., Ahern, J., & Kazmierczak, A. (2011). Multifunctional green infrastructure planning to promote ecological services in the city. *Landscape and Urban Planning, 100*(3), 296–300. https://doi.org/10.1016/j.landurbplan.2011.01.005

32. Santamouris, M. (2014). Cooling the cities – A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. *Solar Energy, 103*, 682–703. https://doi.org/10.1016/j.solener.2012.07.003

33. United Nations Human Settlements Programme (UN-Habitat). (2020). *Enhancing urban resilience through nature-based solutions*. UN-Habitat. https://unhabitat.org

34. World Bank. (2021). *Climate-resilient urban development: Policy and investment strategies for sustainable cities*. World Bank Publications. https://www.worldbank.org https://doi.org/10.1017/9781009325844

ANALYSIS OF SPATIAL METRICS, INDICES (NDVI/NDBI), AND MEAN TEMPERATURE BY URBAN ZONE (LCZ)

ORIG_FID	LCZ		BFPA_SQM	RA_SQM	BA_SQM	Location	BSF	ISF	PSF	ABH_M	ARW_M	AR	SVF_Est	LST_Mean	NDVI_Mean	NDBI_Mean	Average
0	1. Compact Highrise	1	8958.109	10312.175	31355.685	Near Batukeshwar Garden	28.569	32.888	38.543	8.793	15.115	0.582	0.652	60.000	0.082	0.011	18.523
1	1. Compact Highrise	1	10764.117	8239.838	31355.760	Bombay Bazar, Pinjara Bakhal Main Road	34.329	26.279	39.392	11.400	9.150	1.246	0.372	60.200	0.068	0.025	18.246
2	1. Compact Highrise	1	15080.031	6744.768	31355.718	Near Kanch Mandir, Hukumchand Marg	48.093	21.510	30.396	10.600	8.000	1.325	0.353	60.000	0.060	0.033	18.037
3	1. Compact Highrise	1	10503.313	8779.136	31355.719	Near Jinsi Chauraha	33.497	27.999	38.504	10.824	8.029	1.348	0.348	60.000	0.091	-0.009	18.063
6	1. Compact Highrise	1	13818.474	6188.097	31355.657	Narnoli Dharmshala, Mahavir Sports (Kailash Marg)	44.070	19.735	36.195	10.448	7.667	1.363	0.344	60.000	0.069	0.009	17.990
8	1. Compact Highrise	1	11480.569	6484.187	31355.881	Mahesh Book Depot, Navlakha Road	36.614	20.679	42.707	7.129	7.636	0.934	0.472	60.031	0.074	0.014	17.629
9	1. Compact Highrise	1	15363.821	6816.658	31355.929	Prachintam Shani Mandir, Juni Indore	48.998	21.740	29.262	7.575	7.950	0.953	0.465	60.030	0.067	0.019	17.706
10	1. Compact Highrise	1	14011.298	6344.410	31355.963	Fidvi Steels, Hathipala Main Road	44.685	20.234	35.082	7.263	8.500	0.854	0.505	60.400	0.072	0.011	17.760
11	1. Compact Highrise	1	16220.308	7229.750	31355.927	Daulatganj Main Road	51.730	23.057	25.213	11.589	7.500	1.545	0.308	60.200	0.062	0.030	18.123
13	1. Compact Highrise	1	13871.330	8453.252	31355.973	Near Sardar Patel Bridge, Chhoti Gwaltoli	44.238	26.959	28.803	9.583	13.200	0.726	0.567	60.300	0.059	0.031	18.447
14	1. Compact Highrise	1	14821.069	9585.789	31355.911	Novelty Market, Kothari Market	47.267	30.571	22.162	12.498	9.000	1.389	0.339	60.000	0.076	0.018	18.332
15	1. Compact Highrise	1	14393.580	8007.784	31355.938	Indore GPO, Nayapura Main Road	45.904	25.538	28.558	7.296	7.731	0.944	0.468	59.912	0.075	0.012	17.644
17	1. Compact Highrise	1	12094.295	8194.338	31355.745	Near Lodhi Dharmshala, Sadar Bazar	38.571	26.133	35.295	7.376	7.650	0.964	0.460	60.000	0.078	0.013	17.654
74	1. Compact Highrise	1	5194.742	6274.610	31356.655	Nariman Point Residential Society, Nipania Main Road	16.567	20.010	63.423	7.200	8.333	0.864	0.501	60.000	0.119	-0.016	17.700
76	1. Compact Highrise	1	11129.755	8796.605	31356.413	Near The Havelock Hotel, Road No. 3, Vijay Nagar	35.494	28.054	36.452	6.815	7.500	0.909	0.482	59.600	0.095	0.000	17.540
77	1. Compact Highrise	1	8193.528	9814.129	31356.437	TVS-Satbhaiya Vehicles, Shehnai Garden, Near AB Road, Vijay Nagar	26.130	31.299	42.571	9.372	20.906	0.448	0.745	59.700	0.083	-0.020	19.123
78	1. Compact Highrise	1	5690.211	7059.884	31356.361	Scheme 78 Vijay Nagar	18.147	22.515	59.338	8.542	7.781	1.098	0.414	59.800	0.110	-0.020	17.773
Unit 1	2. Compact Midrise	2	20792.206	12849.992	58901.355	56 Chhappan Dukaan, Chandni Chowk	35.300	21.816	42.884	15.357	11.196	1.372	0.342	59.418	0.093	-0.003	18.777
Unit 10	2. Compact Midrise	2	10461.747	5741.961	31356.373	Club Mithya, Near Mangal City Mall, Near Vijay Nagar Square	33.364	18.312	48.324	8.045	7.500	1.073	0.422	59.943	0.095	0.007	17.708
Unit 11	2. Compact Midrise	2	13140.270	5520.234	31355.960	Siddhivinayak Ganesh Mandir, Bhanwarkua	41.907	17.605	40.488	7.241	7.607	0.952	0.465	59.686	0.087	0.008	17.605
Unit 12	2. Compact Midrise	2	12898.843	7351.031	31355.976	Itsy Hotels Phenix, Near Pipliya Rao Ring Road, Near Bhanwarkua	41.137	23.444	35.419	8.036	8.036	1.000	0.447	59.471	0.081	0.006	17.708
Unit 13	2. Compact Midrise	2	10768.254	4492.579	31355.915	Maruti Suzuki Service (Patel Motors), Near Chitwad Road, Near Bhanwarku	34.342	14.328	51.330	8.211	7.500	1.095	0.415	59.971	0.083	0.014	17.729
Unit 14	2. Compact Midrise	2	8774.579	7467.118	31355.924	The Meera, Near AB Road, Near Bholaram Ustaad Marg	27.984	23.814	48.202	9.672	7.500	1.290	0.361	60.000	0.077	0.015	17.892
Unit 15	2. Compact Midrise	2	15037.836	6520.619	31355.959	Bholaram, Near AB Road, Near Bholaram Ustaad Marg	47.958	20.795	31.246	7.956	7.750	1.027	0.438	59.583	0.071	0.011	17.684
Unit 16	2. Compact Midrise	2	14084.528	5911.786	31356.257	Near Hotel Kanchan Tilak, Chandni Chowk	44.918	18.854	36.229	9.650	7.853	1.229	0.377	59.735	0.102	0.000	17.895
Unit 2	2. Compact Midrise	2	15985.942	6201.312	31355.918	Ranipura, Near Khatipura Square	50.982	19.777	29.241	10.722	7.600	1.411	0.334	60.400	0.073	0.030	18.057
Unit 3	2. Compact Midrise	2	8277.573	6962.173	31356.259	Apna Sweets, New Palasia Road	26.398	22.203	51.398	9.600	8.375	1.146	0.400	59.000	0.109	-0.021	17.861
Unit 4	2. Compact Midrise	2	8073.626	8764.060	31356.295	Near Decathon Sports Indore, Near Nafees Restaurant, Old Palasia	25.748	27.950	46.302	7.467	19.100	0.391	0.788	59.000	0.130	-0.036	18.684
Unit 5	2. Compact Midrise	2	14456.399	7857.518	31356.229	Prestige Public School, Near Colonel Phadnis Garden	46.104	25.059	28.837	7.618	7.500	1.016	0.442	59.000	0.107	-0.015	17.567
Unit 6	2. Compact Midrise	2	12306.256	7231.528	31356.238	KK Vigyan and Vyavsaik Adhyayan Mahavidyalaya, Scheme 54 Garden, Ana	39.247	23.062	37.691	7.099	7.650	0.928	0.474	58.971	0.103	-0.018	17.521
Unit 7	2. Compact Midrise	2	12758.373	6857.498	31356.321	Near Apollo Hospital Indore, SICA School Road, Scheme 74 Park	40.688	21.870	37.442	7.471	7.875	0.949	0.466	59.000	0.120	-0.027	17.585
Unit 8	2. Compact Midrise	2	7336.686	4836.821	31356.384	Podar International School, Zostel Indore, Near IDA Park	23.398	15.425	61.177	7.527	7.875	0.956	0.464	59.000	0.108	-0.004	17.593
Unit 9	2. Compact Midrise	2	12605.207	7447.572	31356.307	Near Bhandari Hospital and Research Center, Street No. 19, 54 Park	40.200	23.751	36.049	9.295	7.615	1.221	0.379	59.971	0.095	0.002	17.858
Unit 1	3. Compact Lowrise	3	47161.833	26686.804	115984.199	Koyla Bakhal Park, Nandlalpur Chauraha, Pandhrinath Chowk	40.662	23.009	36.329	11.459	9.150	1.252	0.371	60.000	0.079	0.011	18.232
Unit 2	3. Compact Lowrise	3	16107.141	5036.717	31355.789	Ratan Sev Bhandar/Vijay Chaat House-Sarafa (Sarafa Night Food St/Dhan G	51.369	16.063	32.568	10.618	7.625	1.393	0.338	60.000	0.060	0.027	18.006
Unit 3	3. Compact Lowrise	3	17894.962	5543.596	31355.837	Peergali/Tilak Path (Near Rajwada)	57.071	17.680	25.250	11.854	7.667	1.546	0.308	60.000	0.069	0.026	18.147
Unit 4	3. Compact Lowrise	3	10259.581	5137.497	31355.990	Siyaganj, Warehouse Road, Sarwate Bus Stand	32.720	16.384	50.896	9.669	7.929	1.219	0.379	60.081	0.066	0.018	17.936
Unit 5	3. Compact Lowrise	3	16071.279	6189.732	31355.766	AB Stitching, New Bismillah Hotel, Juna Pitha Main Road	51.255	19.740	29.005	10.997	7.500	1.466	0.323	60.000	0.062	0.031	18.038
Unit 6	3. Compact Lowrise	3	16941.549	9319.674	31355.821	Chicha Indore, Nirmal Garments, Near Imali Bazaar	54.030	29.722	16.248	9.245	8.172	1.131	0.404	59.944	0.062	0.013	17.897
Unit 1	4. Open Highrise	4	13319.434	16465.703	57568.502	Bombay Hospital (Maharaja Chhatrasal Square)	23.137	28.602	48.261	13.200	14.596	0.904	0.484	59.565	0.104	-0.023	18.883
Unit 2	4. Open Highrise	4	8219.362	5951.371	31356.500	Radisson Blu Hotel/Effotel by Sayaji (MR 10/Eastern Ring Road))	26.213	18.980	54.808	18.960	11.625	1.631	0.293	59.457	0.098	-0.031	19.203
Unit 3	4. Open Highrise	4	7812.197	7199.963	31356.468	Indian Coffee House/Shreemaya Celebrity (Shri Badalchand Mehta Marg)	24.914	22.962	52.124	14.000	12.409	1.128	0.405	59.000	0.133	-0.039	18.704
Unit 4	4. Open Highrise	4	8557.189	7428.078	31356.448	Babita Outcall Massage SPA Indore (Near AB Road)	27.290	23.689	49.021	11.845	7.950	1.490	0.318	59.361	0.099	-0.022	18.104
Unit 5	4. Open Highrise	4	8356.699	8420.473	31356.428	Shri Satya Sai Vidya Vihar (Shri Satya Sai School Square)	26.651	26.854	46.495	16.800	14.143	1.188	0.388	60.000	0.098	-0.015	19.260
Unit 6	4. Open Highrise	4	4893.632	3804.211	31356.492	Playotel Premier Vijay Nagar	15.606	12.132	72.261	9.438	7.750	1.218	0.380	59.000	0.125	-0.014	17.790
Unit 7	4. Open Highrise	4	7999.497	2376.146	31355.280	Tata Consultancy Services (Near Super Corridoor)	25.512	7.578	66.909	10.080	7.500	1.344	0.349	59.000	0.145	-0.032	17.839
Unit 8	4. Open Highrise	4	10816.514	5256.353	31356.467	Gift Mania (Vasant Vihar Colony)	34.495	16.763	48.741	8.540	7.667	1.114	0.410	59.000	0.102	-0.027	17.680
Unit 9	4. Open Highrise	4	6730.917	4956.076	31356.415	Mangal City Mall (Near Vijay Nagar Square)	21.466	15.806	62.729	12.000	7.773	1.544	0.308	60.200	0.063	-0.010	18.188
Unit 1	5. Open Midrise	5	32091.994	30574.444	81335.669	Mitti Cafe Organic Fresh Desi (Co Gandharva Guru Chauhan Marg)	39.456	37.590	22.953	10.305	8.582	1.201	0.384	58.923	0.101	-0.010	17.949
Unit 2	5. Open Midrise	5	61599.103	54550.845	159085.350	LIG Colony/MIG Colony (MIG Main Road)	38.721	34.290	26.989	8.056	8.009	1.006	0.445	59.350	0.096	-0.013	17.695
Unit 3	5. Open Midrise	5	24369.208	14846.802	61945.233	Chandni Chowk	39.340	23.968	36.692	12.390	9.214	1.345	0.349	59.061	0.100	-0.012	18.245
Unit 4	5. Open Midrise	5	6945.301	6084.795	31356.209	The Recovery Hospital (Near Veer Savarkar Square)	22.150	19.405	58.445	16.723	8.250	2.027	0.239	59.000	0.122	-0.032	18.633
Unit 5	5. Open Midrise	5	12395.851	6670.970	31356.291	Jayanti Mata Mandir (Near LIG Colony)	39.532	21.275	39.193	9.156	7.600	1.205	0.383	59.000	0.090	0.000	17.743
Unit 6	5. Open Midrise	5	13573.807	8337.142	31356.322	Ashadeep Hospital (Near Atal Bihari Vajpayee Stadium)	43.289	26.588	30.123	9.497	7.688	1.235	0.375	58.417	0.089	0.004	17.730
42	10. Heavy Industries	6	5476.005	8186.784	31356.550	Tata Motors Car Showroom-Jagdish Automotive, Lasudiya Mori, Dewas Na	17.464	26.109	56.428	4.050	15.000	0.270	0.880	60.029	0.098	-0.010	18.032
43	10. Heavy Industries	6	18355.165	5489.858	31356.611	Shree Balaji Distributors Indore, Lasudiya, Dewas Naka	58.537	17.508	23.955	4.015	7.500	0.535	0.683	60.778	0.078	0.029	17.362
44	10. Heavy Industries	6	18550.819	5718.223	31356.635	Shree Radhey Group of Pharmaceutical C and F, Lasudiya	59.161	18.236	22.603	3.938	7.500	0.525	0.690	60.235	0.090	0.020	17.300

RADHA DWIVEDI

EVALUATING HEAT RISK IN URBAN AREAS

Journal Paper submission

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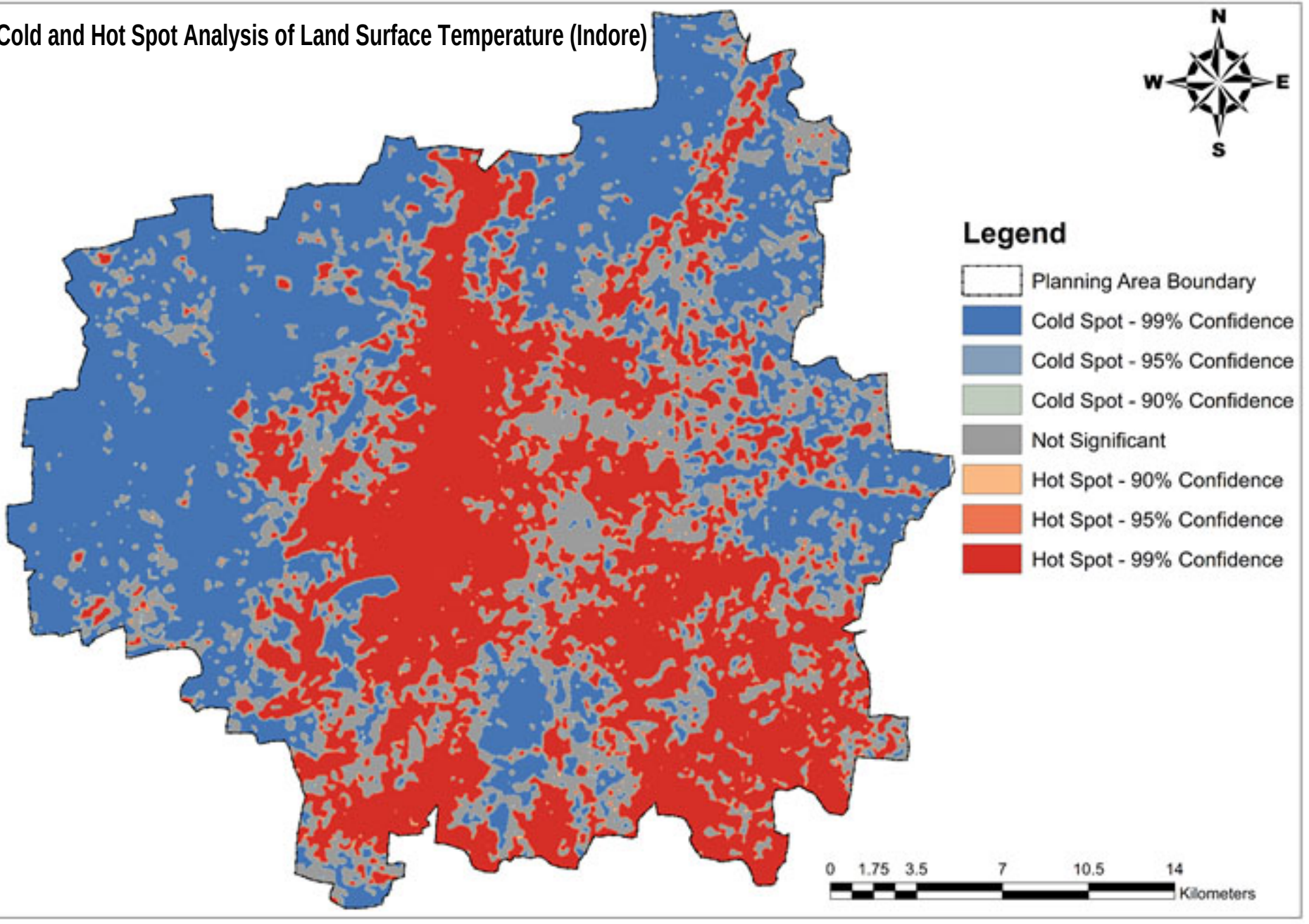
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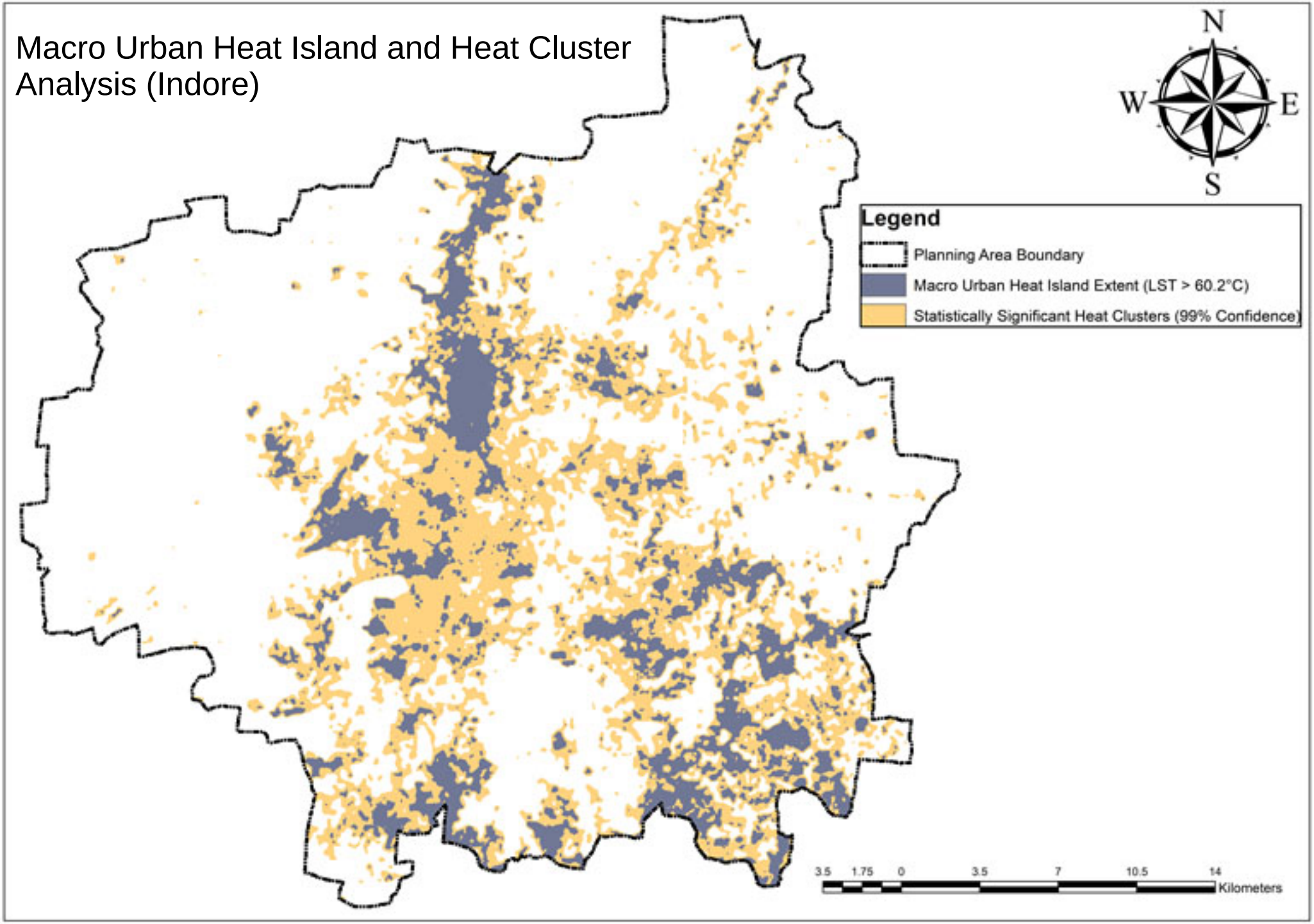
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Cold and Hot Spot Analysis of Land Surface Temperature (Indore)




Macro Urban Heat Island and Heat Cluster Analysis (Indore)
N
W
E
S
Legend
Planning Area Boundary
Macro Urban Heat Island Extent (LST > 60.2°C)
Statistically Significant Heat Clusters (99% Confidence)
3.5 1.75 0 3.5 7 10.5 14
Kilometers

Local Climate Zone (LCZ) Classification Map

N
W E
S

Legend

Municipal Boundary Indore

Planning Area Boundary

Local Climate Zones

10: Heavy Industry

1: Compact Highrise

2: Compact Midrise

3: Compact Lowrise

4: Open Highrise

5: Open Midrise

6: Open Lowrise

7: Lightweight Lowrise

8: Large Lowrise

9: Sparsely Built

A: Dense Trees

B: Scattered Trees

C: Bush, Scrub

D: Low Plants

E: Bare Rock or Paved

F: Bare Soil or Sand

G: Water

0 2 4 8 12 16

Kilometers

Land Surface Temperature Map _2025

N
W E
S

Legend

Municipal Boundary Indore

Planning Area Boundary

Land Surface Temperature

Temperature in °C

35-38 °C (Low Temperature)

38-41 °C(Moderate Temperature)

41-44 °C (High Temperature)

44-46 °C (Very High Temperature)

46-48 °C (Extreme Heat)

0 2 4 8 12 16

Kilometers

Normalized Difference Built-up Index (NDBI) _2025

N
W E
S

Legend

Planning Area Boundary

NDBI

Ranging (-1 to 1)

- -1 to 0.5 (Dense Vegetation)
- -0.5 to -0.2 (Sparse Vegetation)
- -0.2 to 0 (Bare Land)
- 0.2 to 0.5 (Water Body and Low Built-Up)
- 0.5 to 1 (High Built-Up)

0 2 4 8 12 16
Kilometers

Normalized Difference Vegetation Index (NDVI) _2015

N
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Legend

Planning Area Boundary

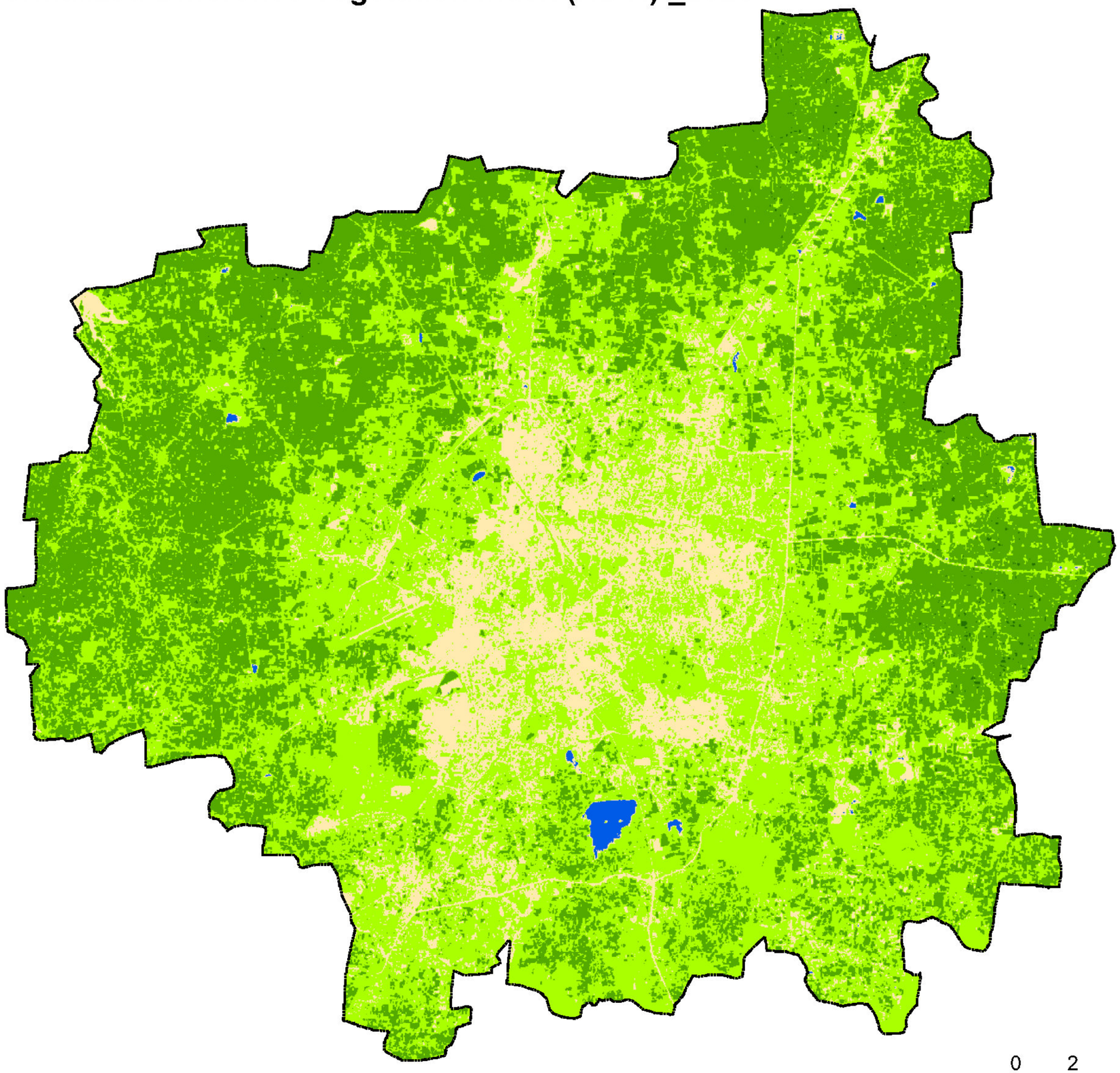
NDVI 2015

Ranging (-1 to 1)

- 0.5 to 0.7 (Dense Vegetation)
- 0.3 to 0.5 (Moderate Vegetation)
- 0.1 to 0.3 (Sparse Vegetation)
- 0 to 0.1 (Bare Land/Built-Up)
- -1 to 0 (Water Body)

0 2 4 8 12 16
Kilometers

Normalized Difference Vegetation Index (NDVI) _2025



N
W
E
S

Legend

Planning Area Boundary

NDVI

Ranging (-1 to 1)

- -1 to 0 (Water Bodies)
- 0 to 0.1 (Bare Land / Built-Up)
- 0.1 to 0.3 (Sparse Vegetation)
- 0.3 to 0.5 (Moderate Vegetation)
- 0.5 to 0.7 (Dense Vegetation)

0 2 4 8 12 16

Kilometers