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GIS-Based Spatial Optimization of Potential Urban Green Spaces for Regulating Urban Heat Island Dynamics : A case of Chennai

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Key words :

Open and green spaces

GIS

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Spatial Optimization & Identification

Buffer Analysis

Green Space Deficiency

analysis identifies priority areas for green infrastructure interventions and provides a practical decision-support framework for mitigating UHI, improving thermal comfort, and promoting climate-resilient urban planning in Chennai.

ABSTRACT :

Rapid urbanization in Chennai has led to declining urban green spaces, intensifying the Urban Heat Island (UHI) effect and reducing environmental sustainability. This study develops a Geographic Information System (GIS)-based framework to identify and prioritize open and green space deficiency areas for UHI mitigation. Landsat 8 imagery was used to derive NDVI, NDWI, NDBI, Land Surface Temperature (LST), and UHI, while park accessibility was assessed using **300 m, 500 m, and 800 m** buffer analyses integrated with hotspot and weighted overlay techniques. Although park accessibility improved with increasing buffer distances, several southern and western neighbourhoods remained underserved. The integrated GIS-based

INTRODUCTION

Rapid urbanization increases impervious surfaces and land values, squeezing out public open space. Studies assessing supply and demand reveal a recurring pattern: urban cores face persistent park deficits, whereas city peripheries or wealthier suburban zones maintain larger, more accessible open spaces. [1]. Green space deficiency does not affect all populations equally; low-income communities and vulnerable demographics (such as elderly populations and renters) disproportionately reside in areas with low park accessibility, minimal tree canopy, and higher exposure to urban heat islands [2].

While global frameworks such as the World Health Organization (WHO)

recommend a minimum of 9 Sq.m green space per capita. The Urban and Regional Development Plans Formulation and Implementation (URDPFI) Guidelines recommend that cities should provide 10–12 Sq.m of green space per capita, exhibit some of the lowest per capita green spaces in Asia, cities like Mumbai and Chennai dropping 1.5 – 2 Sq.m per inhabitant in many wards due to dense high-rise redevelopment and informal settlements. Remote sensing studies revealed 8.6% drop in vegetated cover across Kolkata and Howrah, establishing a direct correlation between green space deficits and increased localized heat stress. Studies conducted in Indian cities reveal alarming statistics regarding green space availability. In Nagpur, the average recreational public green space is only 3.65 m² per person, which is far below the URDPFI recommendation. Some planning zones in the city provide as little as 0.3 m² per person, and only one out of ten planning zones meets the recommended green space standards. Modern urban growth patterns frequently cause acute green space and open space deficiencies, directly weakening the urban ecosystem's natural cooling capacity. Rapid urbanization in Indian cities has resulted in the loss and fragmentation of urban green spaces, intensifying the Urban Heat Island (UHI) effect..

Studies from Bengaluru, Kolkata, and Mumbai consistently show that urban parks and green infrastructure significantly reduce land surface temperatures by approximately 2–3°C and provide cooling benefits extending several hundred metres beyond their boundaries. However, unequal distribution and continuous depletion of green spaces have increased thermal stress, reduced climate resilience, and heightened heat-health risks in many Indian metropolitan areas, highlighting the need for strategic urban greening as a key climate adaptation measure.

The expansion of impervious surfaces through urbanization has significantly altered the thermal characteristics of Indian cities. Remote sensing analyses using Landsat-derived Land Surface Temperature (LST) and vegetation indices have shown a strong inverse relationship between vegetation cover and surface temperature. As vegetation decreases and built-up density increases, urban temperatures rise, intensifying the Urban Heat Island effect. National-scale analyses across Indian cities indicate that vegetation cover remains one of the most influential factors controlling UHI intensity, emphasizing the importance of conserving and restoring urban green spaces as part of sustainable urban development.

Green infrastructure is increasingly recognized as one of the most effective nature-based solutions for addressing urban heat in rapidly growing cities. The integration of urban parks, green corridors, roadside plantations, green roofs, and urban forests into city planning can substantially reduce surface temperatures, improve air quality, and enhance human well-being.

- How can a GIS-based multi-criteria assessment framework be applied to identify and prioritize urban areas with deficiencies in open green spaces?
- What is the relationship between open green space deficiency and Urban Heat Island intensity, and how can GIS-based spatial analysis support the identification of priority locations for green space implementation?
- How can GIS and geospatial techniques be utilized to identify Urban Heat Island hotspots and determine suitable locations for green infrastructure interventions?

LITERATURE REVIEW

Open space and green spaces

shading and evapotranspiration, reduce air

Year	Definition of Open and Green Spaces	Typology/Classification
2017	Urban green spaces include all urban land covered by vegetation, whether publicly or privately owned, such as parks, gardens, street trees, forests, wetlands, and other natural areas.	Parks, gardens, urban forests, street trees, wetlands, green corridors
2011	Green infrastructure consists of natural and semi-natural areas that provide ecosystem services and environmental benefits in urban and rural landscapes .	Parks, forests, wetlands, green roofs, green walls, ecological corridors
2017	Green spaces are vegetated areas, either managed or natural, within urban environments that provide ecological, recreational, aesthetic, and social functions. .	Parks, gardens, vacant green land, urban forests, cemeteries, institutional green spaces
2015	Urban green spaces comprise vegetated areas within cities that contribute to ecosystem services, biodiversity conservation, and human well-being .	Urban parks, forests, wetlands, agricultural land, riverfronts, urban agriculture
2007	Urban green spaces include all forms of vegetation that improve ecosystem health and human health through ecological and environmental services .	Parks, woodlands, private gardens, greenways, street trees, informal green spaces

Table 1 : Definition Of Open and Green Spaces

Urban open and green spaces are essential components of sustainable urban development, providing ecological, environmental, and social benefits that improve the quality of urban life. These spaces contribute to biodiversity conservation, regulate the urban microclimate, and provide recreational opportunities for residents. However, population growth, and uncontrolled land-use conversion have significantly reduced the availability and accessibility of open green spaces in Indian cities.. A

review of major Indian cities reported per capita green space values of 0.9 Sq.m 10.41 Sq.m /person in Delhi, 9.36 m²/person in Mumbai, 6.61 Sq.m /person in Kolkata, 5.90 Sq.m /person in Surat, 3.31 Sq.m /person in Bengaluru, and 0.93 /person in Hyderabad. In contrast, cities such as Chandigarh (38.0 Sq.m /person) and Gandhinagar (29.77 Sq.m /person) exceed the recommended standards because of their planned urban development and extensive green infrastructure. The shortage of open and green spaces has serious environmental consequences. Green areas help regulate urban temperatures through

pollution, improve stormwater infiltration, and enhance biodiversity. Their decline has intensified the Urban Heat Island (UHI) effect in many Indian cities. Studies have reported summer UHI intensities ranging from 2–5°C in Delhi, 2–3.1°C in Pune, and about 2.5°C in Visakhapatnam, with high population density, extensive road networks, traffic congestion, and limited vegetation identified as the primary causes. .

Table 1 : Definition Of Open and Green Spaces

Deficiency of Open Green Spaces

Deficiency of open green spaces has become a major environmental challenge in rapidly urbanizing Indian cities. Increasing pressure from residential, commercial, and transportation development has led to the conversion of vacant land and vegetated areas into impervious surfaces. Several studies have highlighted that the provision of urban green spaces is often uneven, with densely populated and economically disadvantaged neighborhoods experiencing the greatest shortages.. The absence of standardized definitions, planning guidelines, and assessment frameworks for urban green spaces has limited their effective integration into urban development plans. Researchers

emphasize that evaluating both the quantity and accessibility of green spaces using GIS-based methods is essential for identifying underserved areas and prioritizing future green infrastructure investments.

Urban green-space provision should be evaluated using multiple indicators rather than only per-capita availability. Built-up area, population density, open space, and accessibility collectively determine green-space sustainability and help identify environmentally vulnerable neighbourhoods. Rapid urban expansion alters the spatial distribution of green spaces, creating mismatches between vegetation availability and built-up development. Dense urban morphology is consistently associated with lower greenness and greater environmental inequality.

A study in Bengaluru reported that 19 out of 198 municipal wards had no public park, 36 wards had only one park, and approximately 25–29% of residents lacked access to a park within a comfortable walking distance of 400–800 metres. Bengaluru found that urban green spaces reduce surrounding temperatures by an average of 2.23°C, with cooling effects extending up to 347 metres beyond park boundaries.

Urban expansion and green-space loss

Rapid urban expansion has become one of the primary drivers of urban green-space loss in rapidly developing cities. The conversion of natural landscapes, agricultural land, wetlands, and open spaces into residential, commercial, and transportation infrastructure has fragmented urban green networks and reduced the ecological functions of cities. This transformation not only decreases vegetation cover but also increases impervious surfaces, resulting in higher land surface temperatures (LST), intensified Urban Heat Island (UHI) effects, and declining environmental quality. Studies have shown that uncontrolled urban

growth leads to an uneven spatial distribution of green spaces, particularly in densely populated urban cores where green-space accessibility is limited. Therefore, integrating green infrastructure into urban expansion planning is essential to improve climate resilience, maintain ecosystem services, and ensure equitable access to urban green spaces. These findings support the need for GIS-based spatial planning frameworks that identify green-space-deficient areas and prioritize locations for future green infrastructure development.

Unequal Distribution and Accessibility of Green Spaces

The spatial distribution of green spaces in Indian cities is often highly unequal. Large public parks and recreational spaces are generally concentrated in planned residential areas, institutional campuses, or affluent neighborhoods, while densely populated and economically weaker areas frequently lack adequate access to green infrastructure. A 2024 study by Anna University assessed Green Space Per Capita (GSPC) across Chennai using GIS and remote sensing.

The study found that the city's total green space decreased from 77.09 Sq.Km in 2011 to 62.70 Sq.Km in 2021, representing a loss of 14.39 Sq.Km over ten years. During the same period, the average Green Space Per Capita declined from 11.55 Sq.m /person to 7.42 Sq.m /person, falling below the WHO Standard Open space per capita. Spatial inequality limits the environmental and social benefits that green spaces provide and increases disparities in urban quality of life. Recent studies emphasize that accessibility is as important as the quantity of green space, recommending that every resident should have access to a functional public green space within a reasonable walking distance.

Open Green Spaces and Urban Heat Island Mitigation

Urban green spaces are among the most effective nature-based solutions for mitigating the Urban Heat Island (UHI) effect. Vegetation lowers urban temperatures through shading, evapotranspiration, and the reduction of heat-absorbing impervious surfaces. Numerous studies have demonstrated a strong negative relationship between vegetation cover and land surface temperature. A study conducted by the Indian Institute of Management Ahmedabad analyzed 262 urban green spaces in Bengaluru and found that parks reduce surrounding land surface temperatures by an average of 2.23°C .

Studies in Delhi have also shown that urban forests, parks, and tree-lined streets significantly reduce local temperatures compared to surrounding built-up areas. Satellite-based analyses indicate that areas with high vegetation density, measured using the Normalized Difference Vegetation Index (NDVI), consistently exhibit lower land surface temperatures than areas dominated by concrete and asphalt. .

Role of GIS in Assessing Open Green Space Deficiency

GIS have emerged as one of the most effective tools for assessing the spatial distribution, accessibility, and adequacy of urban green spaces. GIS integrates satellite imagery, land use data, transportation networks, population distribution, and administrative boundaries to produce detailed spatial analyses of urban landscapes. Researchers increasingly employ GIS techniques such as buffer analysis, network analysis, spatial overlay, Normalized

Difference Vegetation Index (NDVI), and land-use classification to evaluate green space availability and identify areas with significant deficiencies. GIS is also widely used to evaluate accessibility to public parks.

GIS and Remote Sensing for Urban Heat Island Assessment

Remote sensing and GIS have become indispensable tools for analyzing Urban Heat Island intensity and understanding its spatial distribution. Thermal satellite imagery from Landsat, MODIS, and Sentinel missions allows researchers to estimate Land Surface Temperature (LST), while vegetation indices such as NDVI and built-up indices such as NDBI

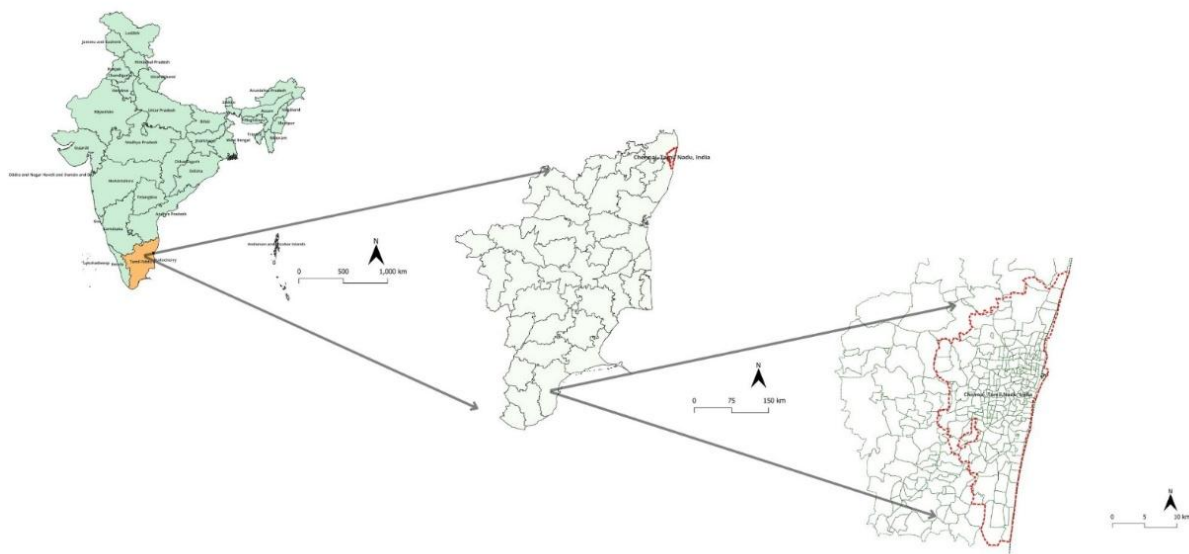


Figure 1: Location of Case Study

help explain temperature variations across urban landscapes. GIS facilitates the integration of these datasets with demographic information, land-use maps, and transportation networks, enabling comprehensive assessments of urban heat exposure. Spatial analyses consistently reveal that areas characterized by dense built-up development, sparse vegetation, and high population density experience the highest temperatures. Studies in Nagpur showed that as the city's built-up area increased from 34.72% in 2005 to 69.43% in 2025, vegetation cover declined to 9.69%, and land surface temperatures increased from approximately 35°C to nearly 52°C. GIS-based spatial analysis clearly demonstrated that areas with lower vegetation cover experienced higher surface temperatures, confirming the role of green spaces in mitigating the Urban

Table 2 : Geo-spatial Maps and these Role

Heat Island effect .

Thematic Layer	Purpose	What It Represents	Role in UHI & Green Space Assessment
NDVI (Normalized Difference Vegetation Index)	Measures vegetation density and health by comparing Near Infrared (NIR) and Red bands. Higher values indicate healthy vegetation.	Measures the density and health of vegetation (values range from -1 to +1). Higher values indicate dense, healthy vegetation.	NDVI is widely used to identify urban green cover and evaluate its cooling effect. Areas with high NDVI generally exhibit lower Land Surface Temperature (LST) because vegetation provides shading and evapotranspiration. It is an essential indicator for assessing the ecological quality of parks and urban green spaces.
NDWI (Normalized Difference Water Index)	Measures the presence of surface water and vegetation moisture content.	Measures the presence of surface water and vegetation moisture content. Higher values indicate more water or moisture.	NDWI identifies water bodies and moisture-rich landscapes that contribute to evaporative cooling. In urban environments, parks with lakes, ponds, wetlands, or moist vegetation generally experience lower temperatures and improve surrounding microclimates .
NDBI (Normalized Difference Built-up Index)	Identifies built-up and impervious urban surfaces such as buildings, roads, and concrete.	Measures the extent of built-up and impervious surfaces. Higher values indicate dense urban development.	High NDBI values indicate dense urbanization and impervious surfaces that absorb and store heat, resulting in higher surface temperatures. Comparing NDBI with NDVI helps identify green space deficiency and urban heat hotspots.
LST (Land Surface Temperature)	Represents the physical temperature of the Earth's surface derived from thermal infrared satellite imagery.	Represents the actual surface temperature of the Earth's surface obtained from thermal satellite imagery.	LST directly quantifies thermal conditions across the city and identifies hotspots. It is the primary dataset used to assess the cooling performance of parks and evaluate thermal stress within different park buffer zones .
UHI (Urban Heat Island)	Represents areas where urban temperatures are significantly higher than surrounding rural or vegetated areas.	Composite map showing areas where urban temperatures are significantly higher than surrounding regions, typically derived by integrating LST with land cover indicators.	UHI maps integrate thermal conditions with land-cover characteristics to identify priority areas for climate adaptation. Parks located within high UHI zones are critical for reducing urban temperatures, improving thermal comfort, and enhancing climate resilience.

GIS-Based Multi-Criteria Decision Analysis for Green Space Planning

Recent advancements in spatial planning have integrated Geographic Information Systems (GIS) with Multi-Criteria Decision

Analysis (MCDA) to support strategic planning for urban green infrastructure. Rather than relying solely on green space availability, GIS-MCDA frameworks incorporate multiple indicators such as land use, population density, land ownership, road accessibility, slope, vacant land availability, environmental sensitivity, and urban heat intensity. By assigning relative weights to these criteria, planners can identify and rank locations according to their suitability for future green space development..

Research Gaps in Literatures

Although numerous studies have documented the environmental benefits of urban green spaces and their role in mitigating Urban Heat Island effects, significant research gaps remain in the Indian context. Most existing studies focus either on mapping green space distribution or analyzing Urban Heat Island patterns independently, with limited

integration between the two .

Furthermore, relatively few studies have developed comprehensive GIS-based decision-support frameworks that simultaneously assess open green space deficiency,

accessibility, Urban Heat Island intensity, and land suitability for future green infrastructure development .

rapid urbanization and infrastructure developments like Metro, BRTS, etc. which leads to Open and green spaces deficiency

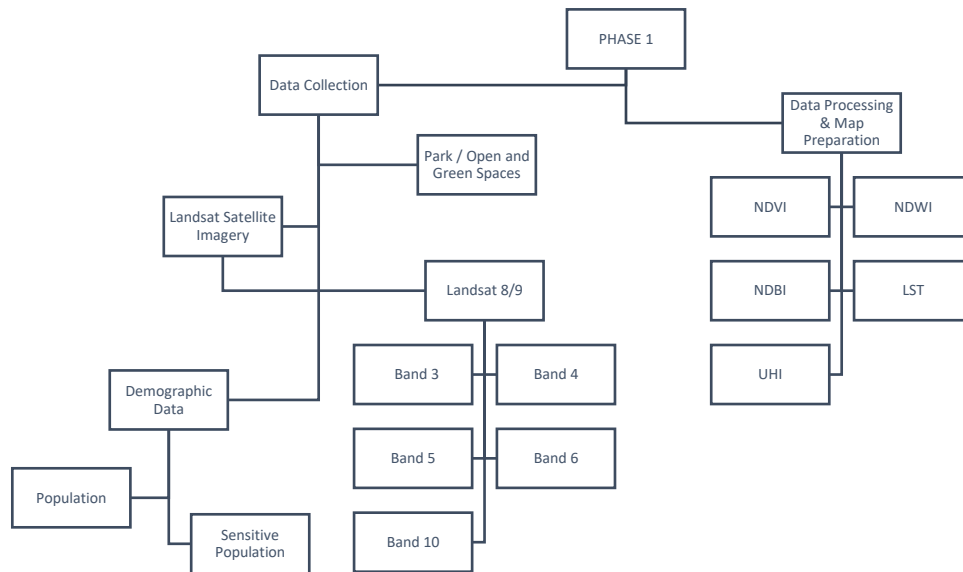


Figure 2: Phase 1 Methodology Diagram

There is also a lack of standardized methodologies for prioritizing intervention areas based on multiple environmental and socio-economic criteria. Addressing these gaps through an integrated GIS-based framework can provide valuable support for evidence-based planning, enabling cities to identify priority locations for green infrastructure while enhancing urban climate resilience and improving equitable access to open green spaces.

Study area : Chennai

From the Figure 1 we see the study area which is Chennai. It is located in the Southern Indian State Tamil Nadu. Chennai is the Capital of Tamil Nadu. The study focuses on the insufficient green space per capita in the Chennai city, which is controlled and monitored by the Greater Chennai Corporation (GCC). It spans approximately 426 Sq.km. Chennai was selected due to its

and urban heat island effect. The city is characterised by open space shortage and flood vulnerability and urban heat island. The specific area of study focuses on Open spaces and green spaces like Parks, Play ground and Beaches.

METHODOLOGICAL FRAMEWORK

METHODOLOGY

Figure 2 Methodology diagram illustrates the step by step guide for Data collection and Data Processing for the Study area. This Methodology gives the structural guide for the Case study to evaluate the open and green spaces.

Data Collection

First Stage focuses on preparing the geospatial database by digitizing the existing Open and Green Spaces (Park, Play Grounds, etc.) And the process of Collecting Landsat 8 satellite Imagery like Band

3,Band 4,Band 5, Band 6, Band 10. From this Landsat 8 Satellite Imagery we can get the Landcover feature like Water body coverage, Built up, Vegetation of the particular study area. This helps to analyse the study area in geospatial way to understand the major issue and causes of the Open and Green spaces Deficiency

Data Processing & Map Preparation

The second stage is Data processing and Map Preparation in this stage. We will prepare various maps to understand the spatial characters of the study area and the

open And Green Spaces which inturn reduces the urban heat.

From the Phase 1 we can gather the Geospatial Database of the study area so that we can move to the further process of identifying and prioritizing the Open and Green spaces. It helps to prepare proper thermal comforted urban environment for the people.

From the Table 2 we can get the information for the Maps and what it represents and how it contributes to the open and green space evaluation.

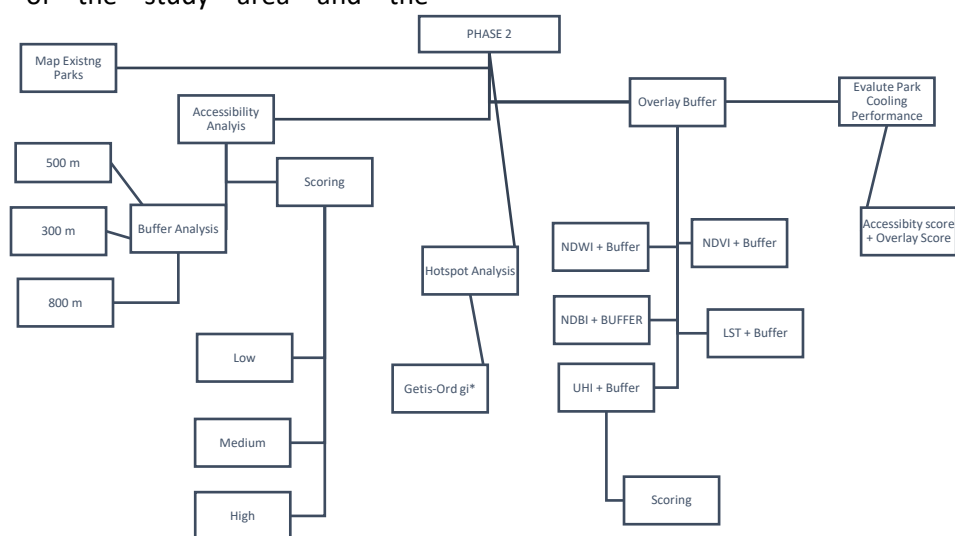


Figure 3 :Phase 2 Methodology Diagram

Preparation of NDVI maps to understand Vegetation Spread of the study area. Its helps to estimate Open and Green spaces. And NDWI map helps us to understand the Water coverage over the study area and NDBI to understand the Builtup cover the study area to identify the dense built up zones to prioritize the zones to reduce the urban heat. And then LST map helps us to understand the study area Land surface temperature provides adequate Open and Green spaces. UHI maps finds the major heat area so that we can provide to

The thematic layers NDVI, NDWI, NDBI, LST, and UHI collectively provide a comprehensive understanding of the spatial relationship between land cover, urbanization, and thermal conditions. NDVI identifies the density and health of vegetation, demonstrating that areas with higher vegetation cover generally experience lower land surface temperatures due to shading and evapotranspiration. Similarly, NDWI highlights the presence of water bodies and moisture, which contribute to localized cooling through evaporative processes and improve the

microclimatic conditions of surrounding urban areas. In contrast, NDBI represents the extent of built-up and impervious surfaces, where higher values are commonly associated with increased heat absorption and storage, leading to elevated surface temperatures. Land Surface Temperature (LST) directly quantifies the thermal characteristics of the study area, enabling the identification of urban heat hotspots and the evaluation of the cooling performance of parks. The Urban Heat Island (UHI) map integrates these thermal and land-cover characteristics to delineate areas experiencing significant heat stress, thereby identifying locations that require priority intervention..

Figure 4 Reflects Distribution of Parks in Case area. Its give the visual illustrate of the various parks locations and these distribution.

Figure 3 Phase 2 Methodology focuses on the geospatial analysis of the study area using Geographic Information System (GIS) platforms, including QGIS, ArcMap, and

accessibility, and environmental significance of existing open and green spaces. This phase establishes the spatial database required to understand the relationship between urban green infrastructure and the Urban Heat Island (UHI) effect. The primary objective is to identify the location, distribution, accessibility, and thermal influence of parks and open spaces, thereby assessing their effectiveness in improving the local microclimate and mitigating urban heat .

The first step of this Figure 3 phase 2 involves the mapping of all existing parks, green spaces, and open spaces within the study area using high resolution spatial datasets and satellite imagery. The mapped data serve as the foundation for subsequent spatial analyses and facilitate the identification of areas with adequate and inadequate green space provision. Following the spatial inventory, an accessibility analysis is conducted to evaluate the service area and influence of each park. Buffer zones of 300 m, 500 m, and 800 m are generated around all identified parks based on commonly accepted

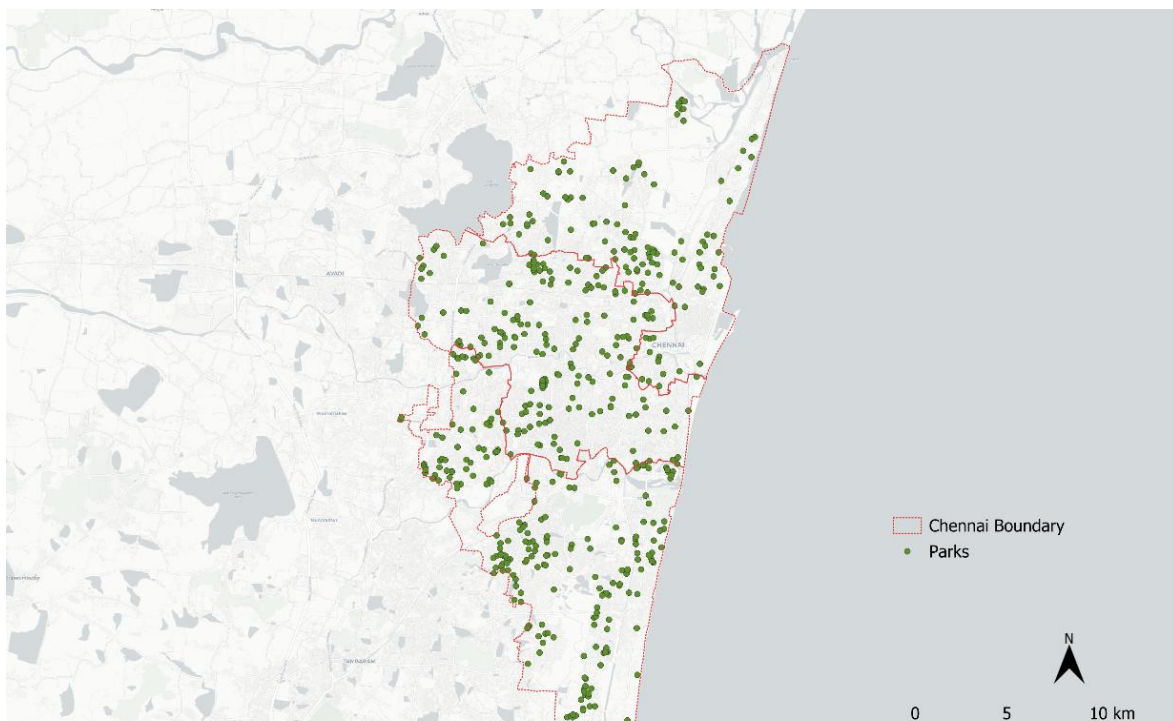


Figure 4 : Distribution Of Parks In Chennai

ArcGIS, to evaluate the spatial distribution,

walking distances in urban planning and green

space accessibility studies. The analysis identifies populations that are adequately served by existing green spaces as well as neighbourhoods experiencing open and green space deficiencies.

Beyond measuring accessibility, the buffer analysis also evaluates the environmental and thermal influence of parks on their surrounding urban environment. By examining the spatial relationship between park buffers and thermal indicators such as Land Surface Temperature (LST), the study assesses how the cooling effect of vegetation varies with distance from the park boundary. The outputs of this phase provide a detailed spatial assessment of park accessibility, service coverage, and environmental performance. These results form the basis for integrating thermal indicators such as NDVI, NDWI, NDBI, LST, and UHI in the subsequent phase, enabling the evaluation and prioritization of parks according to their contribution to Urban Heat Island mitigation.

each park. Based on this assessment, green space deficiency areas are identified by locating regions with high UHI intensity, limited accessibility to parks, low vegetation cover, and high built-up concentration. These deficiency areas are then prioritized according to the severity of their environmental conditions and need for intervention. The prioritization process identifies the most suitable locations for implementing new green infrastructure, such as neighborhood parks, pocket parks, urban forests, and green corridors, to maximize cooling benefits and improve urban thermal comfort. The final outcome is a GIS-Based Green Space Prioritization Framework for UHI Mitigation in Chennai, which serves as a spatial decision support tool for planners and policymakers by providing evidence-based recommendations for enhancing green space distribution, reducing Urban Heat Island intensity, and promoting climate-resilient urban development.

Geo-Spatial Analysis

Following the Research methodology we moving to the analysis part, its consist the various spatial indicating maps. From this Spatial indicating maps we get to know the cities existing condition of Open and Green spaces. This analysis consists of various Geo-spatial Maps and various methods to create the maps and while evaluating the maps we will get the geo-spatial data for the site area.

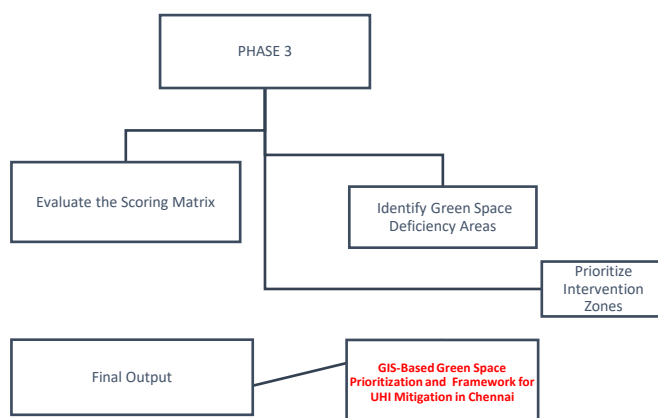


Figure 5 Phase 3 Methodology represents the evaluation and decision-making stage of the research, where multiple spatial analyses are integrated to assess the effectiveness of existing parks in mitigating the

Figure 5: Phase 3 Methodology diagram

Urban Heat Island (UHI) effect. A scoring matrix is developed by combining indicators such as park accessibility, UHI intensity, vegetation cover (NDVI), built-up density (NDBI), and water presence (NDWI) to quantitatively evaluate the environmental performance of

NDVI

Figure 6 represents NDVI map of Chennai(2024), the vegetation index ranges from -0.236 to 0.514 , indicating that the study area consists predominantly of low to moderate vegetation cover, with only a few locations exhibiting relatively high vegetation density. The maximum NDVI value of 0.514 suggests the presence of healthy vegetation in selected areas such as large urban parks, reserve forests, wetlands, institutional campuses, and peri-urban green spaces. Conversely, the minimum value of -0.236 corresponds to water bodies, barren land, and highly impervious built-up surfaces where vegetation is absent. According to standard

Statistically, the spatial distribution of Figure 7 NDVI suggests that urbanized central and eastern parts of Chennai, where residential, commercial, industrial, and transportation infrastructure are concentrated, exhibit relatively lower NDVI values due to extensive impervious surfaces and reduced vegetation cover. In contrast, the southwestern and northwestern peripheral areas show comparatively higher NDVI values because of agricultural lands, reserve forests, wetlands, and larger open spaces. This spatial heterogeneity indicates that vegetation is unevenly distributed across



Figure 6 : NDVI Map of Chennai (2024)

NDVI interpretation, values below 0.0 generally represent water or non-vegetated surfaces, 0.0 – 0.2 indicate barren land and sparse vegetation, 0.2 – 0.4 represent moderate vegetation, and values above 0.4 indicate dense and healthy vegetation. Therefore, the observed NDVI range demonstrates that Chennai is characterized by fragmented green cover with limited areas of dense vegetation.

the city, resulting in ecological fragmentation and reduced continuity of green infrastructure. Such fragmentation limits the cooling effect of vegetation and reduces the ecosystem services provided by urban green spaces .

The maximum NDVI value of 0.514 also indicates that Chennai possesses very few areas with dense vegetation, as values greater than 0.6 , which are typically associated with

dense forests, are absent from the map. This suggests that although green spaces exist within the city, they are insufficient in extent and are spatially isolated rather than forming a connected urban green network. The dominance of moderate NDVI values implies that much of the vegetation consists of scattered parks, roadside trees, institutional campuses, and agricultural patches rather than continuous forest cover. Such a vegetation pattern is typical of rapidly urbanizing metropolitan regions where built-up expansion replaces natural vegetation over time.

From an urban climate perspective, the Figure 6 NDVI map indicates a strong inverse relationship between vegetation density and Urban Heat Island (UHI) intensity. Areas with higher NDVI generally experience lower land surface temperatures due to evapotranspiration, shading, and reduced solar heat absorption, whereas areas with lower NDVI correspond to higher thermal stress caused by extensive built-up surfaces. Recent studies conducted for Chennai reported a continuous decline in vegetation cover accompanied by increasing built-up land and intensifying Urban Heat Island effects. These studies concluded that increasing urban green cover through strategically distributed parks, green corridors, and urban forests is essential for mitigating thermal stress and improving urban microclimate.

NDWI

Based on Figure 7 NDWI (Normalized Difference Water Index) map of Chennai(2024), the spatial distribution of surface water indicates that water resources are concentrated mainly along the Bay of Bengal coastline, major reservoirs (such as Chembarambakkam, Red Hills, Sholavaram, and Puzhal lakes), river corridors (Adyar and Cooum), wetlands, and scattered inland tanks. The NDWI values in the study area range from ≤ -0.3655 to > 0.1577 , demonstrating that the majority of Chennai is dominated by negative NDWI values, while only a limited proportion exhibits positive values associated with open

water bodies. In NDWI analysis, values greater than 0 generally indicate the presence of surface water, whereas negative values represent built-up areas, barren land, roads, and vegetation with comparatively lower surface moisture. Thus, the map indicates that most of the Chennai Metropolitan Area consists of urbanized land with limited surface water coverage, while permanent water bodies are spatially fragmented and unevenly distributed.

From a statistical perspective, the NDWI classification suggests that a large proportion of the city falls within the classes ≤ -0.3655 and -0.3655 to -0.1911 , indicating extensive impervious surfaces and relatively dry urban landscapes. The intermediate class (-0.1911 to -0.0167) represents areas with mixed land cover, including sparse vegetation, agricultural land, and transitional moist surfaces. Only a relatively small percentage of the study area falls within the positive NDWI class (> 0.1577), corresponding to lakes, reservoirs, rivers, wetlands, and the coastal waters of the Bay of Bengal. This distribution reflects Chennai's rapid urban expansion, where built-up development has substantially reduced natural wetlands and surface water connectivity over recent decades.

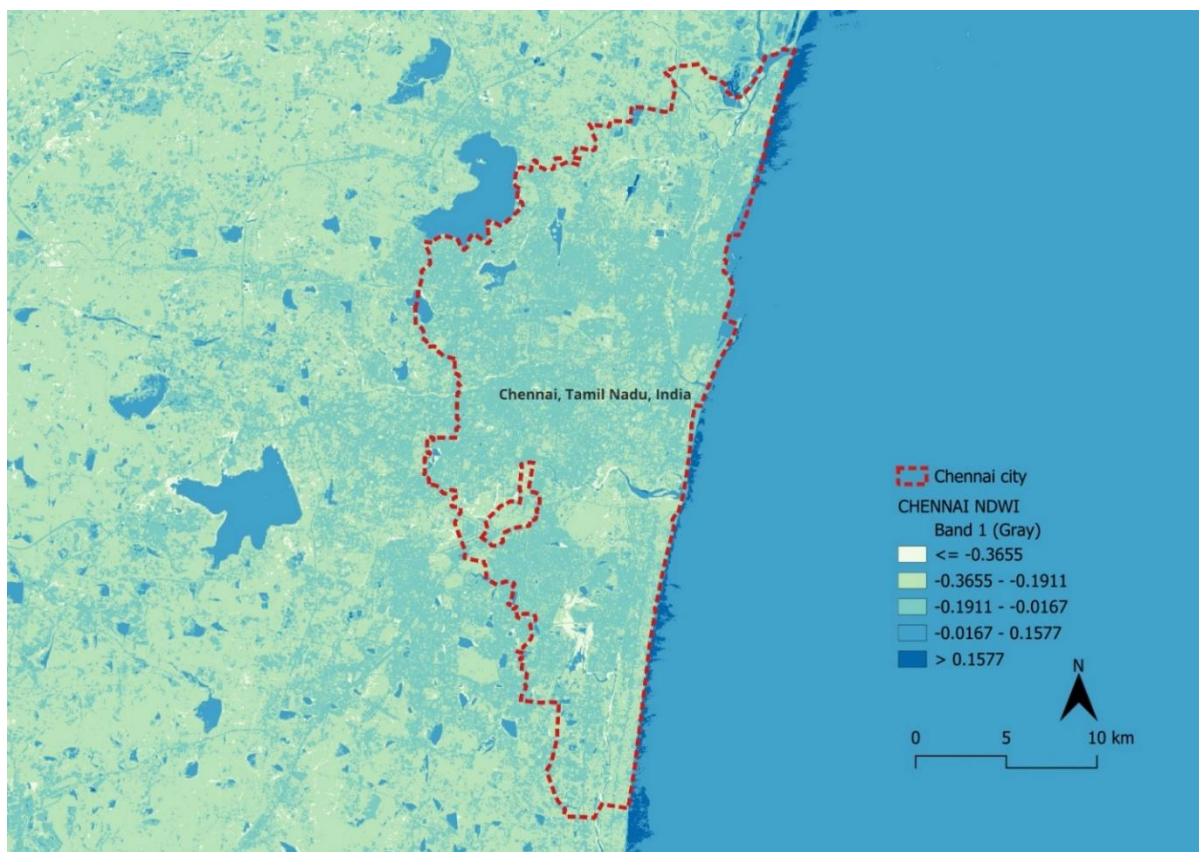


Figure 7 : NDWI Map Of Chennai (2024)

The spatial pattern also reveals that the highest NDWI values are concentrated around major reservoirs and along the eastern coastal belt, whereas the central urban core exhibits predominantly negative NDWI values. This indicates that the dense residential, commercial, industrial, and transportation zones possess limited surface water availability and relatively low moisture content. The discontinuous distribution of positive NDWI patches further suggests fragmentation of Chennai's blue infrastructure, reducing the hydrological connectivity between lakes, wetlands, and drainage systems. Such fragmentation can decrease groundwater recharge, reduce urban cooling through evaporation, and increase the city's vulnerability to both drought and flooding .

From an urban climate perspective, NDWI plays an important role in regulating land surface temperature (LST) and mitigating the Urban Heat Island (UHI) effect. Areas with higher NDWI values generally exhibit lower surface temperatures because water bodies possess higher heat capacity and promote evaporative cooling. Conversely, areas characterized by negative NDWI values correspond to impervious built-up surfaces that absorb and store solar radiation, resulting

in elevated land surface temperatures . Studies conducted for Chennai have consistently reported that the decline in water bodies and wetlands, together with increasing built-up land, has intensified urban heat islands and altered the city's microclimate. Maintaining and restoring lakes, wetlands, and river corridors is therefore considered an essential strategy for improving thermal comfort and climate resilience .

Figure 7 NDWI map indicates that Chennai is predominantly characterized by low surface water availability, with only localized pockets of permanent water bodies. The observed NDWI range (≤ -0.3655 to >0.1577) demonstrates that the city's landscape is dominated by urban development, while blue infrastructure is confined mainly to reservoirs, wetlands, rivers, and coastal areas. When integrated with NDVI, NDBI, LST, park accessibility buffers, and hotspot analysis, the NDWI map provides a valuable indicator for identifying environmentally vulnerable areas where the lack of water bodies and green infrastructure contributes to higher urban temperatures. This integrated GIS-based assessment can support the prioritization of blue-green infrastructure interventions, restoration of wetlands, protection of urban

lakes, and development of climate-resilient planning strategies for Chennai.

NDBI

From Figure 8 The Normalized Difference Built-up Index (NDBI) map of Chennai (2024) represents the spatial distribution of built-up land and impervious surfaces across the city. The NDBI values in the study area range from ≤ -0.2705 to > 0.1645 , indicating a transition from water bodies and vegetated landscapes to densely urbanized built-up areas. In general, positive NDBI values indicate built-up land, while negative values correspond to vegetation, agricultural land, wetlands, and water bodies. The observed

wetlands, rivers, coastal waters, and vegetated areas.

From a statistical perspective, the spatial distribution of NDBI indicates that most of the Chennai Metropolitan Area falls within the moderate built-up class (-0.1255 to 0.0195), reflecting a continuous urban fabric composed of mixed residential, commercial, and institutional land uses. Areas with high NDBI values (0.0195 – 0.1645 and >0.1645) are concentrated mainly in the central, eastern, and southern parts of the city, where urban density, road infrastructure, industrial estates, and commercial developments are dominant. In contrast, the northwestern and southwestern peripheral regions exhibit

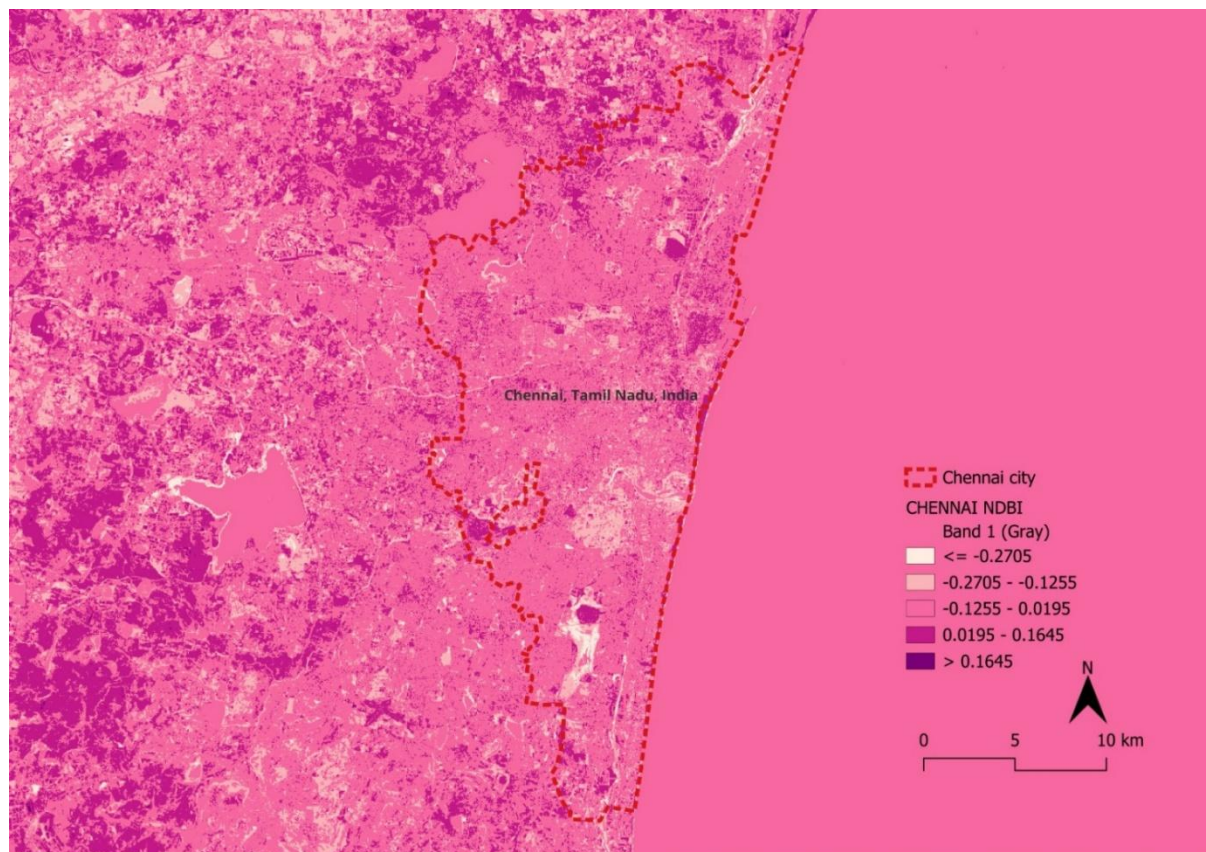


Figure 8 : NDBI Map Of Chennai(2024)

range suggests that Chennai is predominantly an urban landscape with extensive impervious surfaces interspersed with fragmented green and blue infrastructure. The highest NDBI values (>0.1645) represent dense residential, commercial, industrial, and transportation corridors, whereas the lowest values (≤ -0.2705) correspond to major lakes,

comparatively lower NDBI values due to the presence of agricultural land, reserve forests, wetlands, and large water bodies. This spatial variation clearly illustrates the urban expansion gradient from the dense city core towards the less developed peri-urban fringe .

The Figure 8 NDBI map further demonstrates that Chennai has undergone significant

urbanization, resulting in a substantial increase in impervious surfaces. Recent studies reported that the built-up area in Chennai increased from approximately 36% in 2014 to about 67% in 2024, accompanied by a considerable decline in vegetation cover from 25% to nearly 10%. This trend is reflected in the increasing NDBI values observed across the metropolitan region and indicates rapid conversion of agricultural land, wetlands, and open spaces into urban land uses. Such land transformation has reduced ecological connectivity and intensified environmental pressures associated with urban growth .

The spatial pattern of high NDBI values closely corresponds with areas experiencing elevated Land Surface Temperature (LST) and stronger Urban Heat Island (UHI) effects. Impervious materials such as concrete, asphalt, rooftops, and paved surfaces possess high heat storage capacity and low evapotranspiration, resulting in greater heat absorption during the daytime and slower heat release during the night. Consequently, areas with higher NDBI values generally exhibit higher surface temperatures, whereas areas characterized by lower NDBI and higher NDVI or NDWI values tend to remain relatively cooler. Studies conducted in Chennai have consistently identified a strong positive relationship between NDBI and LST, confirming that increasing urbanization significantly contributes to the intensification of the Urban Heat Island phenomenon. One study reported a positive correlation ($R^2 \approx 0.57$) between NDBI and land surface temperature, indicating that built-up expansion is a major driver of urban warming .

The NDBI analysis indicates that Chennai is characterized by a predominantly built-up urban landscape, with NDBI values ranging from -0.2705 to >0.1645 . High-density urban development is concentrated within the metropolitan core, while lower NDBI values are confined mainly to lakes, wetlands, reserve forests, and peripheral agricultural areas. The increasing dominance of built-up land, together with declining vegetation and surface water, highlights the growing environmental challenges associated with rapid urbanization.

When integrated with NDVI, NDWI, LST, park accessibility buffers, and hotspot analysis, the Figure 8 NDBI map provides a robust GIS-based framework for identifying highly urbanized and heat-vulnerable zones, evaluating green-space deficiencies, and prioritizing locations for blue-green infrastructure, park development, urban greening, and climate-resilient planning interventions aimed at mitigating the Urban Heat Island effect.

LST (Land Surface Temperature)

The Figure 9 Land Surface Temperature (LST) map of Chennai illustrates the spatial variation in surface thermal conditions across the metropolitan area. The LST values range from $\leq 15.51^\circ\text{C}$ to $>40.22^\circ\text{C}$, indicating a thermal gradient of approximately 25°C between the coolest and hottest surfaces. The map shows that the majority of Chennai falls within the $30.95\text{--}37.13^\circ\text{C}$ temperature classes, indicating that most of the urban landscape experiences moderate to high surface temperatures. Extremely high temperatures ($>40.22^\circ\text{C}$) occur only in localized hotspots associated with dense built-up areas, industrial zones, transport corridors, and barren land, whereas the lowest temperatures are observed over the Bay of Bengal, major lakes, wetlands, and densely vegetated areas. These patterns are characteristic of rapidly urbanizing coastal cities where impervious surfaces dominate the

urban core. Statistically, the LST distribution demonstrates a clear spatial differentiation between urban heat zones and natural cooling zones. The central, western, and southern urbanized portions of Chennai exhibit predominantly high LST values ranging from 34°C to more than 40°C, reflecting the concentration of residential, commercial, industrial, and transportation infrastructure. In

temperatures. Recent studies conducted in Chennai have reported a strong positive relationship between NDBI and LST ($R^2 \approx 0.57$) and a negative relationship between NDVI and LST, confirming that increasing urbanization and declining vegetation are the primary drivers of Urban Heat Island (UHI) formation. Impervious materials such as asphalt, concrete, and rooftops absorb and retain solar

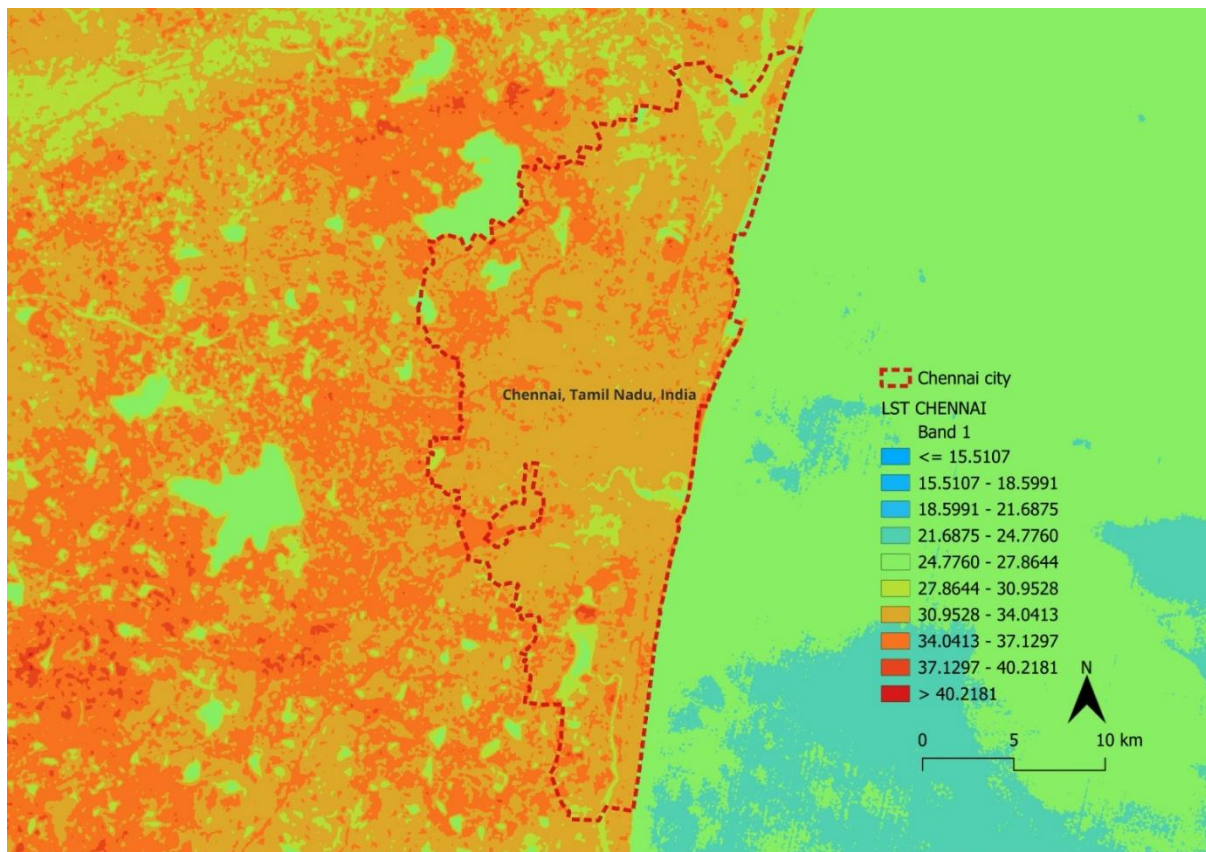


Figure 9 : LST Map Of Chennai(2024)

contrast, relatively lower temperatures (24–31°C) occur along the eastern coastal belt, around major reservoirs, river corridors, wetlands, and urban green spaces due to evaporative cooling and vegetation cover. The coastal influence of the Bay of Bengal also contributes to reduced surface temperatures in the eastern part of the city by moderating the local microclimate .

The thermal pattern strongly reflects the influence of land use and land cover (LULC) on surface temperature. Areas characterized by high NDBI (built-up index) correspond closely with the highest LST values, while regions with higher NDVI (vegetation) and NDWI (surface water) exhibit significantly lower

radiation during the day and release it slowly at night, producing persistent thermal hotspots .

Long-term studies further indicate that Chennai has experienced a substantial increase in thermal stress over the past two decades. Recent satellite-based analysis found that built-up land increased from approximately 36% in 2014 to about 67% in 2024, while vegetation cover declined from 25% to around 10%. This rapid land-use transformation has intensified surface urban heat island conditions throughout the metropolitan area. Another long-term assessment (2001–2022) reported that Chennai's LST increased by approximately 1.61°C over the study period,

with persistent thermal hotspots developing in Anna Nagar, Koyambedu, Ambattur, and other densely urbanized neighborhoods. These findings demonstrate that urban expansion has significantly altered the city's thermal environment.

From an environmental planning perspective, the Figure 9 LST map clearly identifies high-temperature priority zones where thermal stress is greatest. Areas exceeding 37–40°C require targeted interventions such as increasing urban tree canopy, expanding neighborhood parks, restoring wetlands, preserving urban lakes, implementing green roofs and cool roofs, and enhancing permeable surfaces. Conversely, the lower-temperature areas associated with vegetation and water bodies demonstrate the critical role of blue-green infrastructure in mitigating urban heat. These cooling landscapes provide ecosystem services including evapotranspiration, shading, and reduced heat storage, thereby improving urban thermal comfort and climate resilience.

UHI (Urban heat Island)

The Figure 10 Urban Heat Island (UHI) map represents the relative thermal intensity across Chennai by distinguishing warmer urban surfaces from cooler natural landscapes. The UHI values range from $\leq -22.47^{\circ}\text{C}$ to $> 60.28^{\circ}\text{C}$, indicating substantial spatial variability in surface thermal conditions. Negative values correspond primarily to cooling zones, including the Bay of Bengal, major lakes, wetlands, river corridors, and dense vegetation, while positive values represent urban heat hotspots associated with built-up areas. The Figure 10 UHI map indicates that the majority of Chennai falls within the 41.19–53.92 UHI intensity class, suggesting that a large proportion of the metropolitan area experiences moderate to high urban heat stress. Only a limited number of localized hotspots exceed 60.28, representing areas of extreme thermal accumulation. These hotspots are typically associated with dense residential neighborhoods, industrial estates, transportation corridors, and extensive impervious surfaces.

Statistically, the spatial distribution reveals a clear contrast between urban heat hotspots and urban cooling islands. The central, northern, western, and southern urban cores exhibit predominantly high UHI values due to high building density, extensive road networks, limited vegetation, and large impervious surfaces. In contrast, the eastern coastal belt, major reservoirs (Red Hills, Chembarambakkam, Puzhal, and Sholavaram), wetlands, and river corridors display comparatively lower or negative UHI values because of the cooling influence of water bodies and vegetation. The Bay of Bengal further moderates temperatures through sea breeze circulation, producing a distinct coastal cooling effect that reduces thermal intensity in eastern Chennai.

The observed UHI pattern strongly corresponds with land-use characteristics derived from NDVI, NDBI, NDWI, and LST analyses. Areas with high NDBI (dense built-up land) coincide with the highest UHI intensity, whereas regions characterized by high NDVI and NDWI consistently exhibit lower thermal intensity. Recent studies in Chennai reported that built-up land increased from approximately 36% in 2014 to about 67% in 2024, while vegetation cover declined from 25% to nearly 10%. This transformation has resulted in an increase in UHI intensity because impervious materials such as asphalt, concrete, and rooftops absorb, store, and

slowly release solar energy, whereas vegetation and water bodies dissipate heat through shading and evapotranspiration .

Long-term investigations also demonstrate that Chennai's urban thermal environment has intensified considerably over the past two

climate adaptation. Areas exhibiting high UHI intensity (>53.92) require interventions such as expanding neighborhood parks, restoring wetlands, increasing urban tree canopy, developing green corridors, implementing cool roofs and cool pavements, and protecting existing blue-green infrastructure. The

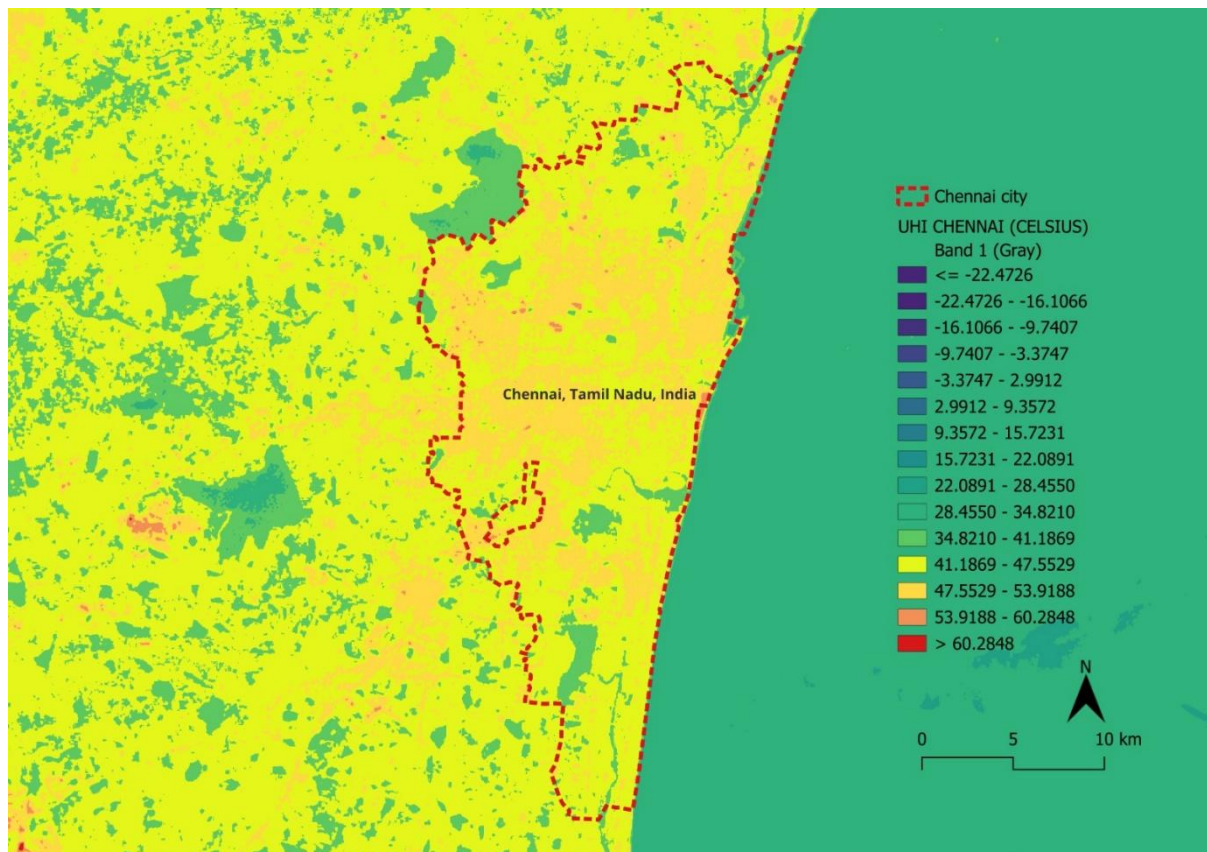


Figure 10 : Urban Heat Island Map Of Chennai(2024)

decades. A study analysing the period 2001–2022 found that Land Surface Temperature increased by approximately 1.61°C, while Surface Urban Heat Island (SUHI) intensity increased from about 0.71°C in 2001 to 1.43°C in 2016. Persistent thermal hotspots were identified in Anna Nagar, Koyambedu, Ambattur, Madhavaram, and Airport regions, whereas Guindy National Park, the Adyar River corridor, and the coastal belt function as significant cooling zones. These findings demonstrate that rapid urbanization, vegetation loss, and expansion of impervious surfaces have significantly altered Chennai's thermal landscape.

From an urban planning perspective, the Figure 10 UHI map identifies priority areas for

extensive cooling influence observed around lakes, rivers, wetlands, and coastal zones highlights the importance of integrating green and blue infrastructure into urban development strategies. These nature-based solutions can significantly reduce surface temperatures, improve thermal comfort, enhance biodiversity, and strengthen climate resilience.

Bufoer Analysis

300 m Buffer Analysis with UHI

The Figure 11 300 m park accessibility hotspot map evaluates the immediate neighborhood-level accessibility of parks and their

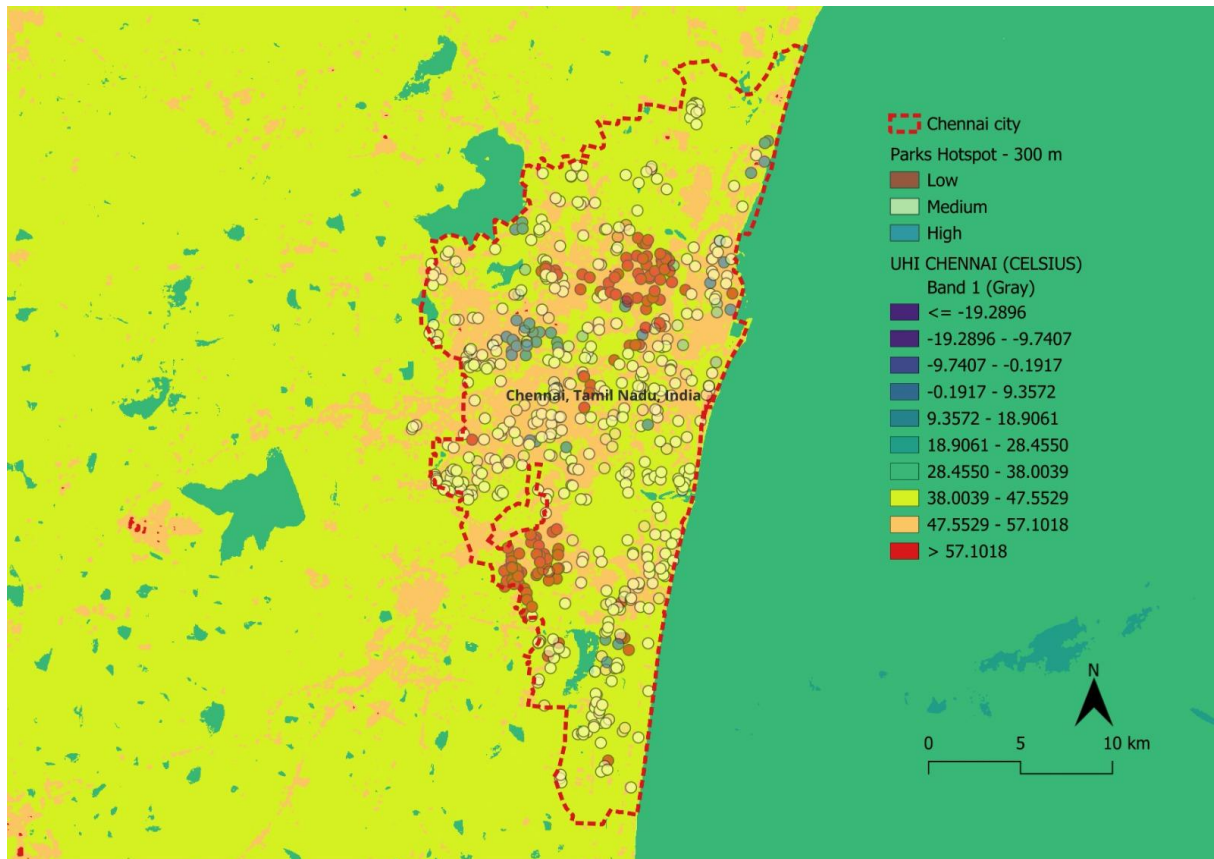


Figure 11 : 300 m Buffer Analysis with UHI Map

relationship with the Urban Heat Island (UHI). A 300 m buffer represents an approximate 5-minute walking distance, which is widely accepted in urban planning as the preferred service radius for neighborhood parks. Overlaying the accessibility hotspots with the UHI layer enables the identification of areas where park provision is either sufficient or deficient in relation to thermal stress.

The spatial distribution indicates that most parks are classified as Medium accessibility hotspots, suggesting that although parks are distributed throughout Chennai, their immediate service coverage is uneven. High-accessibility hotspots (blue) are concentrated mainly in the central-western parts of the city, where clusters of parks provide overlapping 300 m service areas. These locations coincide with comparatively lower UHI intensity because dense green infrastructure enhances shading, evapotranspiration, and surface cooling. Research has shown that park cooling effects generally extend 200–300 m from park boundaries, making the 300 m buffer

particularly effective for assessing neighborhood thermal benefits. The average park cooling distance reported in recent studies is approximately 277 m, supporting the use of a 300 m accessibility threshold.

Conversely, the Figure 11 map identifies several Low-accessibility hotspots (red) in the central, south-central, and northeastern parts of Chennai, where clusters of parks are limited despite relatively high UHI intensity. These areas experience greater exposure to heat because residents have fewer green spaces within walking distance. The overlap of low park accessibility with high UHI classes (approximately 47–57°C and locally >57°C in the normalized UHI raster) indicates neighborhoods where urban greening interventions are most urgently required. Similar studies in Chennai have reported that areas with limited vegetation and increasing impervious surfaces consistently experience higher land surface temperatures and stronger Urban Heat Island effects.

The analysis further demonstrates a clear relationship between park accessibility and thermal resilience. Areas containing clusters of neighborhood parks generally correspond to relatively lower UHI values because vegetation reduces surface temperature through canopy shading and evapotranspiration. In contrast, neighborhoods lacking parks within the 300 m walking distance remain dominated by impervious surfaces, resulting in higher heat accumulation. International studies have concluded that equitable access to urban parks is an essential component of Urban Heat Island mitigation and environmental justice, particularly in densely populated cities.

500 m Buffer Analysis with UHI

The Figure 12 500 m park accessibility hotspot map represents park accessibility within an

closely clustered and provide overlapping service areas. In contrast, low-accessibility hotspots are observed in the central, southern, and northeastern parts of the city, many of which coincide with high Urban Heat Island (UHI) intensity.

This spatial relationship suggests that neighborhoods with inadequate park access experience greater thermal stress due to limited vegetation and extensive impervious surfaces. The 500 m buffer demonstrates that increasing park accessibility can significantly enhance urban cooling, reduce heat exposure, and improve environmental quality. Therefore, areas exhibiting low park accessibility and high UHI should be prioritized for the development of new parks, green corridors, urban forests, and other Nature-Based Solutions (NBS) to improve climate resilience and thermal

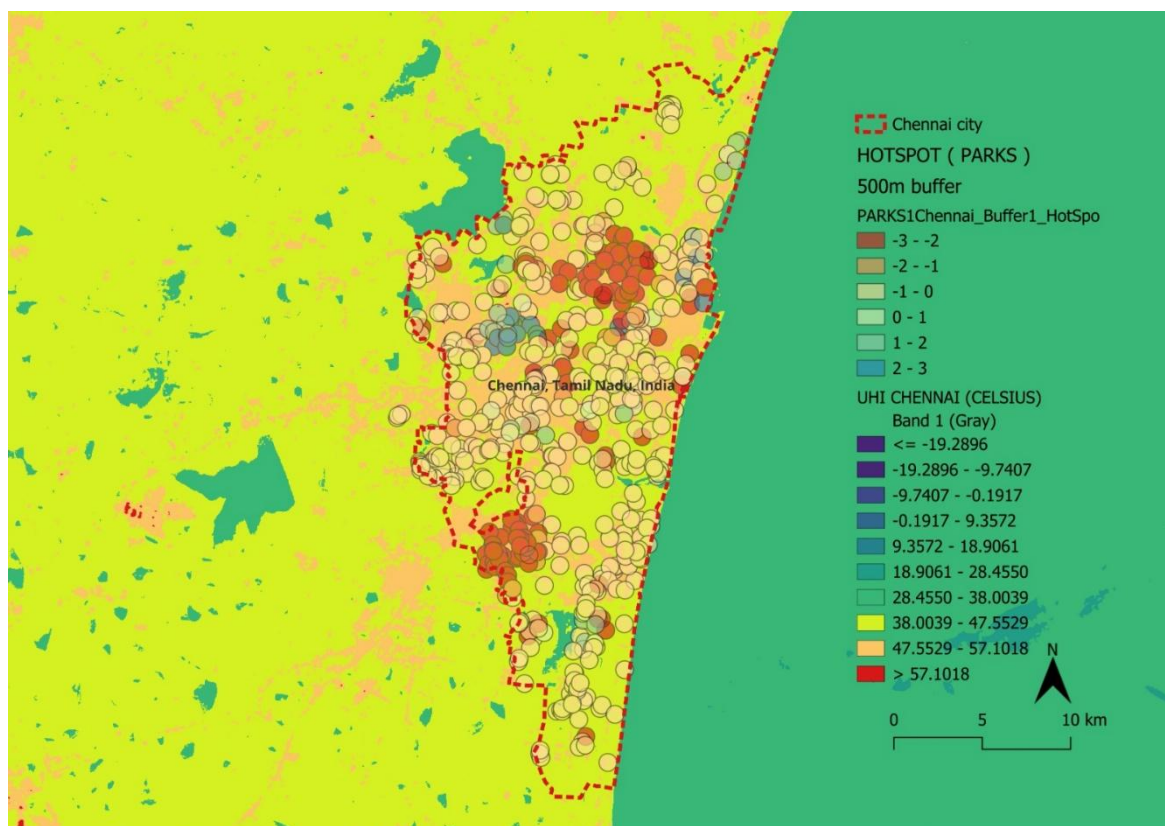


Figure 12 : 500 m Buffer Analysis with UHI Map

approximate 8–10 minute walking distance and shows a broader service coverage compared to the 300 m buffer. The analysis indicates that medium-accessibility parks dominate most parts of Chennai, while high-accessibility hotspots are concentrated mainly in the central-western region, where parks are

comfort. Similar studies have reported that urban parks provide significant cooling benefits within 300–500 m of their boundaries, making the 500 m buffer an effective planning standard for evaluating neighborhood park accessibility and mitigating Urban Heat Island effects.

800 m Buffer Analysis with UHI

The Figure 13 800 m park accessibility hotspot map represents park accessibility within an approximate 10–15 minute walking distance, providing the broadest service coverage among the three buffer scenarios. The analysis shows that medium-accessibility parks

instead, additional parks and green corridors are required in underserved neighborhoods to effectively reduce urban heat. Previous studies have demonstrated that the cooling influence of large urban parks can extend up to 800–1000 m, although the cooling intensity decreases with distance, making the 800 m buffer suitable for evaluating city-scale

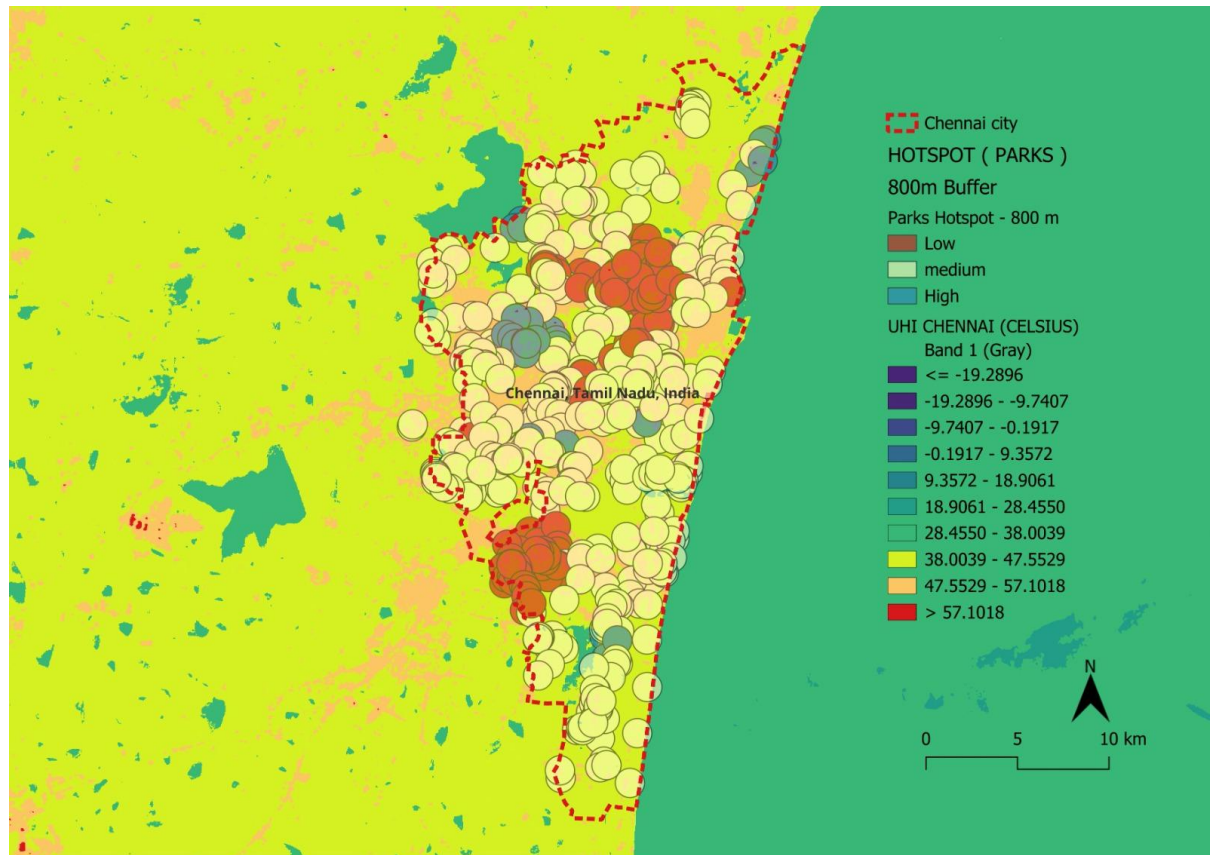


Figure 13 : 800 m Buffer Analysis with UHI Map

dominate most parts of Chennai, indicating that a large proportion of the population has access to parks within the recommended walking distance. High-accessibility hotspots are concentrated in the central-western region, where park clusters create extensive overlapping service areas and correspond to relatively lower Urban Heat Island (UHI) intensity. However, low-accessibility hotspots remain evident in the central, south-central, and northeastern parts of the city, where limited green space availability overlaps with higher UHI zones, indicating persistent green infrastructure deficiencies despite the larger buffer distance. The findings suggest that increasing the accessibility radius alone cannot eliminate disparities in park distribution;

accessibility and thermal resilience.

Overlay Analysis

The integrated overlay map combines Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), Normalized Difference Water Index (NDWI), and Land Surface Temperature (LST) to identify the spatial distribution of environmentally vulnerable and thermally resilient areas within Chennai. The composite overlay values range from -0.415 to 0.309 , indicating a continuous gradient from environmentally favorable (cooling) zones to environmentally stressed (heat-prone) zones. Negative values represent areas dominated by vegetation and surface water with lower land surface temperatures, whereas positive values indicate landscapes characterized by dense built-up surfaces, limited vegetation, reduced moisture availability, and higher thermal conditions. This integrated approach provides a comprehensive assessment of urban environmental quality by simultaneously

Statistically, the Figure 14 overlay map indicates that most of Chennai falls within intermediate composite values, reflecting a heterogeneous urban landscape where built-up land, scattered vegetation, and isolated water bodies coexist. Areas exhibiting positive overlay values (0.10 – 0.309) are concentrated predominantly in the central, southern, and western urban core, corresponding to high-density residential, commercial, industrial, and transportation corridors. These zones are characterized by high NDBI, low NDVI, low NDWI, and elevated LST, indicating greater environmental stress and stronger Urban Heat Island (UHI) intensity. In contrast, negative overlay values (-0.415 to -0.10) occur mainly around major lakes, wetlands, river corridors, reserve forests, and coastal areas, where higher vegetation density and surface moisture contribute to lower surface temperatures and improved ecological conditions.

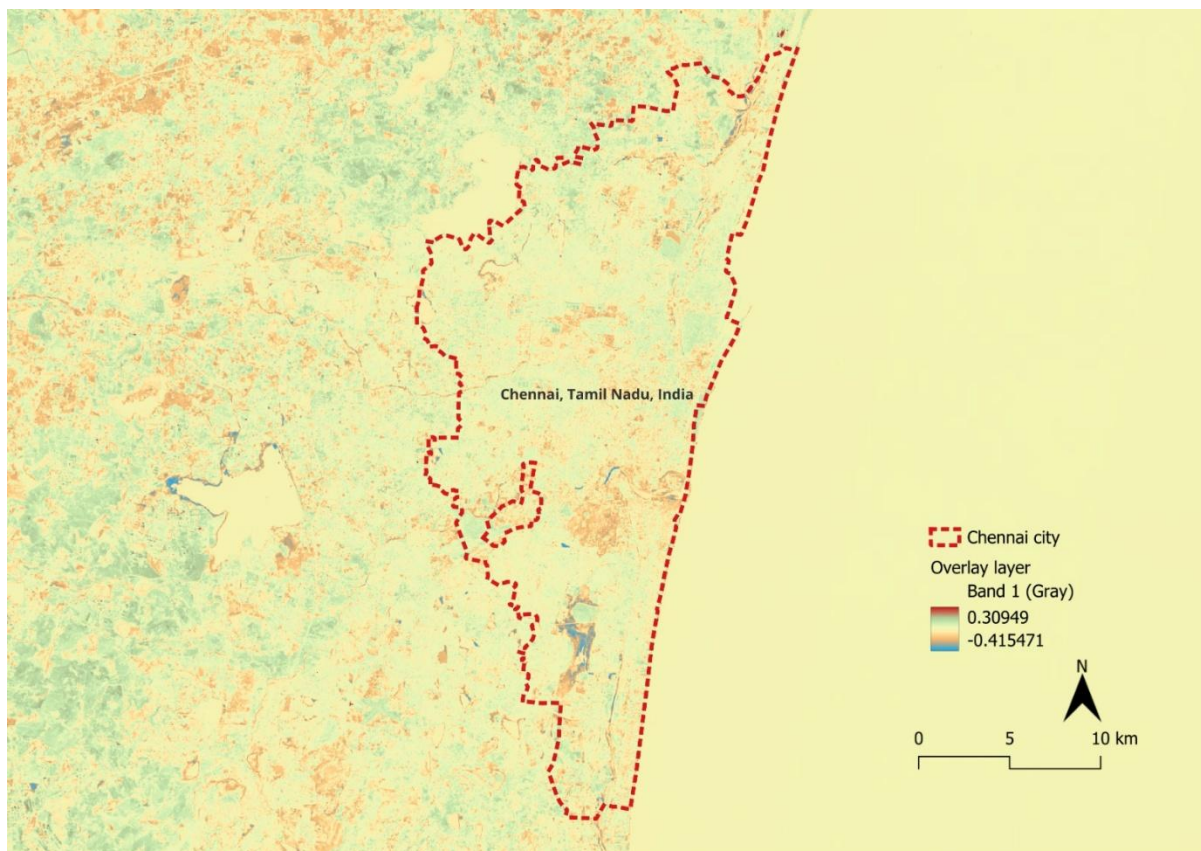


Figure 14 : Overlay of NDVI+NDWI+NDBI+LST+UHI

considering vegetation, built-up intensity, water availability, and thermal characteristics.

The spatial pattern demonstrates a strong interaction between green infrastructure, blue

infrastructure, built-up expansion, and thermal characteristics. Areas with high NDVI and NDWI consistently correspond to lower overlay values because vegetation provides shading and evapotranspiration, while water bodies promote evaporative cooling. Conversely, regions with high NDBI exhibit positive overlay values due to the dominance of impervious surfaces that absorb and retain solar radiation, resulting in elevated LST. Studies conducted in Chennai consistently report a negative correlation between NDVI and LST and a positive correlation between NDBI and LST, confirming that vegetation reduces urban temperatures whereas built-up expansion intensifies the Urban Heat Island effect. The Tamil Nadu Urban Cooling Guidelines similarly demonstrate that increasing vegetation lowers surface temperature, while increasing built-up density raises LST .

Recent investigations further indicate that Chennai has experienced substantial land-use transformation over the past decade. Scientific Reports (2026) reported that the built-up area increased from approximately 36% in 2014 to 67% in 2024, while vegetation cover declined from 25% to nearly 10%. These changes have produced increasing LST and stronger Surface Urban Heat Island intensity across the metropolitan region. Likewise, studies observed a 13.33% reduction in urban vegetation accompanied by a 6.53°C increase in land surface temperature between 2013 and 2022, emphasizing the importance of preserving green and blue infrastructure in rapidly urbanizing cities.

From a planning perspective, the integrated overlay map provides a multi-criteria environmental suitability assessment for identifying priority intervention zones. Areas with higher positive composite values represent neighborhoods where dense urban development, limited vegetation, reduced water availability, and elevated temperatures combine to create environmentally stressed conditions. These locations should be prioritized for urban greening, development of neighborhood parks, restoration of wetlands

and lakes, street-tree planting, green roofs, cool pavements, and enhancement of permeable surfaces. Conversely, areas with lower negative composite values function as existing ecological assets that should be protected because they contribute significantly to urban cooling, groundwater recharge, biodiversity conservation, and climate resilience.

Discussion

Spatial Distribution of Parks in Chennai

The spatial distribution of parks in Chennai is heterogeneous, with parks concentrated primarily in the central, north-central, and southern parts of the city, while the western and peripheral regions exhibit relatively sparse park coverage. The map indicates that parks are not uniformly distributed, resulting in noticeable spatial inequalities in the provision of urban green spaces. A high density of parks is observed within the central urban core, where parks are closely spaced and form continuous clusters. These areas represent established urban neighborhoods with better access to recreational and ecological green spaces. Similarly, the southern part of the city contains another significant concentration of parks, indicating relatively good spatial availability of green infrastructure in these localities.

In contrast, the western, northwestern, and some southeastern peripheral areas contain fewer parks with greater distances between them. These regions exhibit fragmented and isolated park patterns, suggesting lower accessibility to public green spaces and a less connected green network. Such spatial disparities indicate an imbalance in park provision across the city. The park distribution pattern suggests that Chennai's green infrastructure is clustered rather than evenly dispersed. The concentration of parks in selected urban zones and the scarcity of parks in peripheral areas highlight the need for a more balanced spatial distribution to ensure equitable access to open and green spaces throughout the city. This spatial pattern

provides a foundation for identifying park-deficient areas and prioritizing future green space development.

Open and Green Space deficiency in Chennai

The spatial analysis of Chennai using Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), and Urban Heat Island (UHI) maps provides a comprehensive understanding of the city's green space distribution and its influence on the urban thermal environment. The integrated interpretation of these indices reveals that Chennai is experiencing a considerable deficiency of green spaces, particularly within its highly urbanized core. The NDVI map indicates that vegetation is unevenly distributed across the study area, with healthy and dense vegetation confined mainly to major water bodies, institutional campuses, wetlands, and the peripheral regions. In contrast, much of the municipal area exhibits low NDVI values, reflecting sparse vegetation and fragmented green patches that are insufficient to provide effective ecological and climatic benefits.

The NDBI map further demonstrates that built-up land dominates the urban landscape, signifying extensive urban expansion and increasing impervious surfaces. Rapid population growth, infrastructure development, commercial expansion, and residential construction have progressively replaced natural vegetation with concrete structures, asphalt roads, and other impervious materials. This transformation has reduced the city's capacity to regulate microclimatic conditions and maintain ecological balance. The reduction of vegetated areas has also diminished the ecosystem services provided by urban green spaces, including carbon sequestration, air purification, stormwater management, biodiversity conservation, and recreational opportunities.

The consequences of green space deficiency are clearly reflected in the LST and UHI maps.

The LST map illustrates elevated surface temperatures throughout much of the urban area, while cooler temperatures are predominantly associated with vegetated zones, lakes, and the coastal belt. Vegetation plays a vital role in regulating surface temperature through shading and evapotranspiration; therefore, its scarcity contributes directly to increased thermal stress. Similarly, the UHI map highlights pronounced heat accumulation across densely built-up regions, confirming that areas with limited vegetation experience stronger urban heat island intensity. Conversely, regions with higher vegetation density exhibit relatively lower temperatures, emphasizing the cooling effect of urban greenery.

The spatial relationship among NDVI, NDBI, LST, and UHI demonstrates a clear inverse correlation between vegetation cover and land surface temperature, and a positive correlation between built-up intensity and urban heat. Areas characterized by high NDVI generally correspond to lower LST and weaker UHI intensity, whereas areas with high NDBI coincide with elevated temperatures and stronger heat island effects. These patterns indicate that the current distribution of green spaces is inadequate to offset the thermal impacts of rapid urbanization and land-use change.

The observed green space deficiency has important environmental, social, and public health implications. Increased surface temperatures contribute to higher energy consumption for cooling, deterioration of air quality, thermal discomfort, and heightened risks of heat-related illnesses, particularly among vulnerable populations. Fragmented and limited green infrastructure also reduces habitat connectivity, threatens urban biodiversity, and weakens the city's resilience to climate change. Furthermore, unequal distribution of green spaces may lead to disparities in environmental quality and quality of life across different neighborhoods.

Overall, the analysis suggests that Chennai requires strategic enhancement of its urban

green infrastructure to mitigate the adverse impacts of urbanization and climate change. Increasing tree canopy cover, developing new urban parks, preserving wetlands and water bodies, restoring degraded green areas, establishing green corridors, promoting rooftop and vertical greening, and integrating nature-based solutions into urban planning can substantially improve the city's environmental sustainability. Expanding and connecting green spaces would not only reduce land surface temperatures and urban heat island intensity but also enhance ecological resilience, improve public health, support biodiversity conservation, and contribute to the long-term livability and sustainability of Chennai.

Overlay Map Indication

Based on the Urban Heat Island (UHI), Land Surface Temperature (LST), and the overlay map (NDVI, NDBI, LST, UHI, and NDWI), the spatial distribution of the Urban Heat Island in Chennai demonstrates a strong relationship between vegetation cover, built-up intensity, surface temperature, and water bodies. The UHI map indicates that the highest heat intensity is concentrated within the densely urbanized municipal area, particularly across the central, southern, and eastern parts of Chennai. These regions are characterized by positive UHI values, reflecting elevated temperatures caused by the concentration of impervious surfaces such as buildings, roads, and other urban infrastructure. In contrast, relatively lower UHI intensity is observed along the coastal belt, around major lakes, wetlands, and peripheral green areas, where vegetation and water bodies contribute to surface cooling through evapotranspiration and evaporative cooling processes.

The LST map further supports this spatial pattern by showing that the urban core predominantly experiences land surface temperatures between 31°C and 40°C, with localized hotspots exceeding 40°C. Cooler surface temperatures are observed over water bodies, coastal regions, and vegetated landscapes, confirming the moderating

influence of natural land cover on urban temperature. The coincidence of high LST zones with areas of intense urbanization highlights the direct impact of impervious surfaces on heat accumulation.

The overlay map integrating NDVI, NDBI, LST, UHI, and NDWI provides a comprehensive representation of the interactions among land cover characteristics and urban thermal conditions. Areas exhibiting high NDBI values (dense built-up land) generally correspond with low NDVI values, high LST, and strong UHI intensity, indicating that urban expansion and the replacement of vegetation with impervious materials significantly enhance heat accumulation. Conversely, areas with high NDVI and high NDWI values, representing vegetated landscapes and water bodies, coincide with lower surface temperatures and reduced UHI intensity. These findings demonstrate a clear inverse relationship between vegetation and urban heat, while showing a positive relationship between built-up density and thermal intensity.

The integrated analysis reveals that the Urban Heat Island effect in Chennai is primarily driven by rapid urbanization, loss of vegetation, and the expansion of impervious surfaces. The spatial correspondence between high UHI intensity, elevated LST, high built-up density, and low vegetation cover confirms that insufficient green infrastructure has reduced the city's natural cooling capacity. Water bodies and remaining green spaces function as localized cooling islands; however, their fragmented distribution limits their ability to offset heat across the metropolitan area. These results emphasize the importance of preserving existing green spaces, restoring wetlands, increasing urban tree cover, and incorporating green infrastructure into future urban planning strategies to mitigate UHI intensity, improve thermal comfort, and enhance climate resilience in Chennai.

300 m Buffer with Open and Green Space Deficiency Map

The Figure 15 300 m buffer analysis map represents the immediate accessibility of parks and green spaces within Chennai. The map indicates that areas covered by high hotspot buffers are spatially associated with zones exhibiting relatively low open and green space deficiency, demonstrating that neighbourhoods located within short walking distances of parks generally experience better green infrastructure availability.

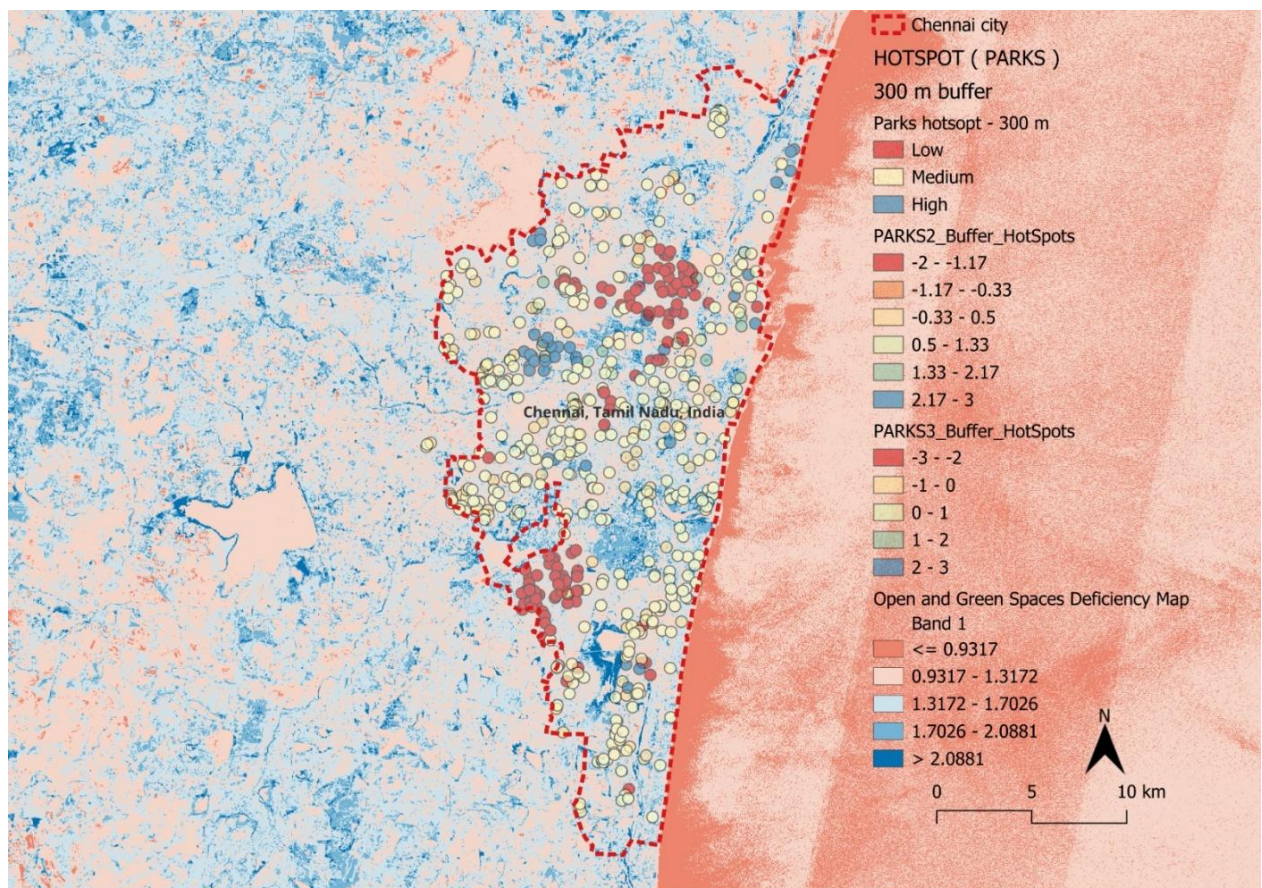


Figure 15 : 300 m Buffer + Hotspot Analysis of Open and Green Spaces Deficiency Map

However, the limited spatial extent of the 300 m buffer leaves a substantial portion of the city outside effective park service areas. Large sections of the southern, south-western, and peripheral urban regions continue to fall within moderate to high deficiency classes despite the presence of scattered parks. These results suggest that the current park distribution is highly localized and does not adequately serve many residential neighbourhoods. Consequently, the 300 m service radius highlights significant spatial inequalities in green space accessibility across Chennai.

500 m Buffer with Open and Green Space Deficiency Map

many rapidly urbanizing areas continue to experience inadequate green space provision.

Figure 16 500 m buffer analysis map demonstrates an improved level of park accessibility compared to the 300 m analysis.

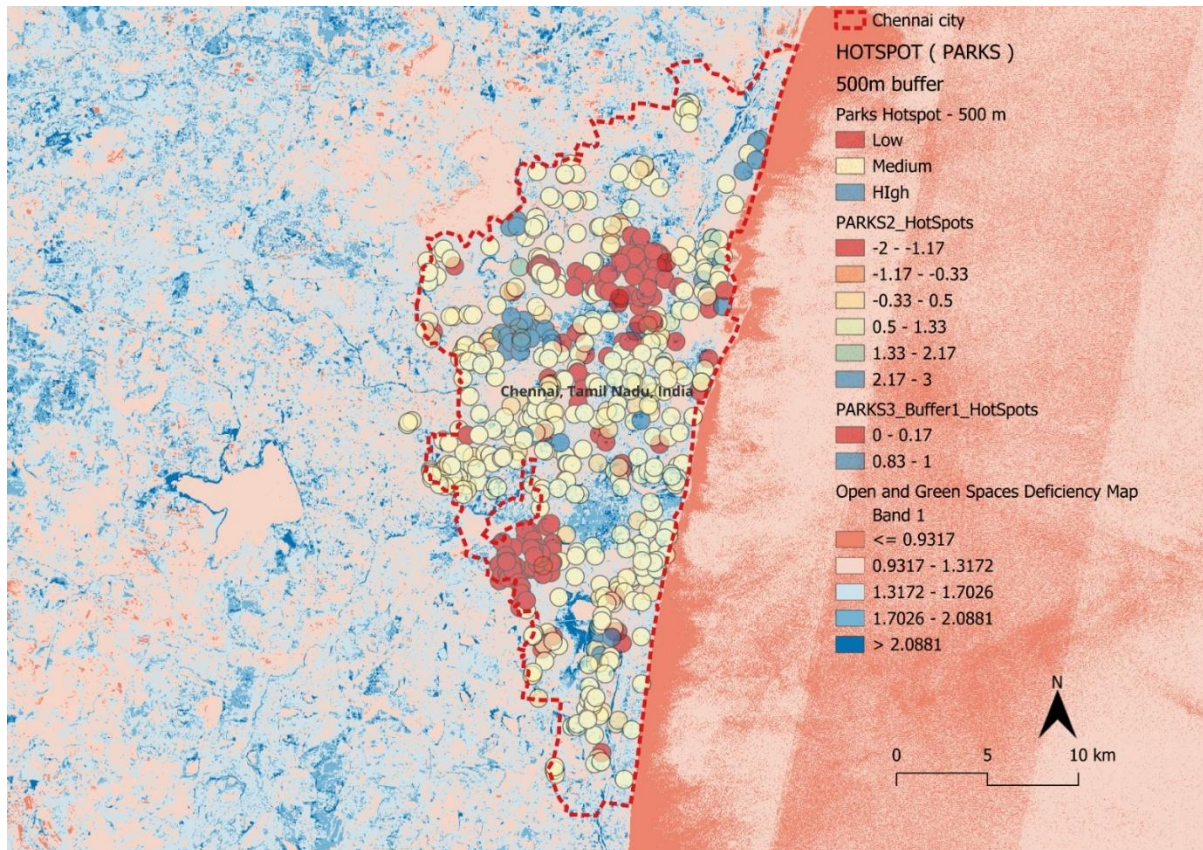


Figure 16 : 500 m Buffer + Hotspot Analysis of Open and Green Spaces Deficiency Map

Increasing the service radius expands the coverage of park influence across central and eastern Chennai, reducing the extent of high-deficiency zones around several established green spaces. Medium hotspot clusters are observed to overlap predominantly with areas classified as moderate deficiency, indicating that parks within a 500 m walking distance provide meaningful environmental benefits to nearby neighbourhoods.

Nevertheless, extensive high-deficiency regions remain evident in the southern and western sectors where park density is comparatively low. These observations indicate that although accessibility improves with a 500 m service distance, the spatial distribution of parks remains uneven, and

800 m Buffer with Open and Green Space Deficiency Map

The Figure 17 800 m buffer analysis map provides the broadest representation of park accessibility and shows the greatest spatial overlap with areas exhibiting low to moderate open and green space deficiency. The expanded buffer substantially increases the proportion of the city that falls within park influence, particularly across central Chennai where several park clusters collectively enhance accessibility. Despite this increased coverage, the deficiency map reveals that numerous peripheral areas, especially along the southern urban fringe and certain western neighbourhoods, continue to exhibit high

deficiency values even within the extended

for walkable green spaces. The 800 m buffer

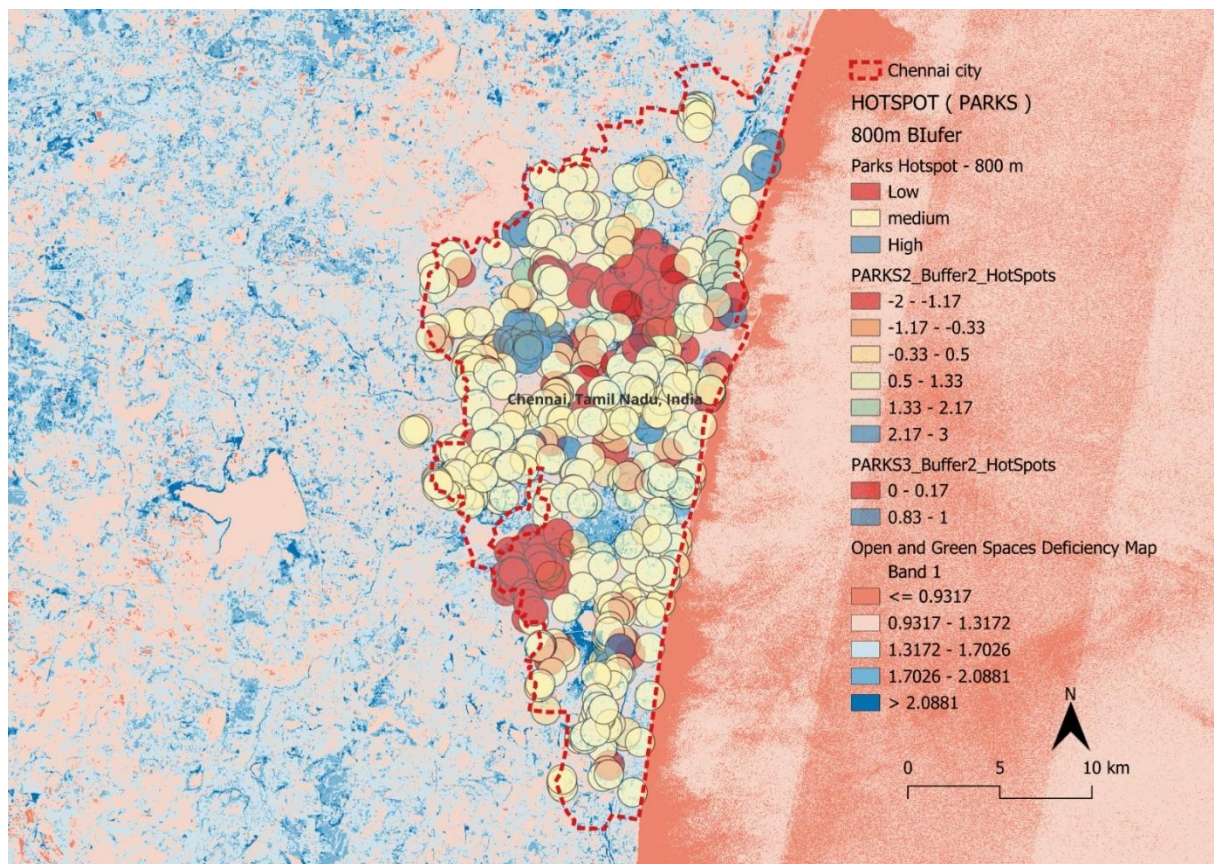


Figure 17 : 800 m Buffer + Hotspot Analysis of Open and Green Spaces Deficiency Map

service radius. This indicates that greater travel distance alone cannot compensate for the insufficient number and uneven distribution of parks.

The persistence of highly deficient zones within the 800 m buffer suggests that the primary issue is not only accessibility distance but also the lack of adequately sized and strategically distributed green spaces.

Comparative Interpretation of Buffer Distances

Comparison of the three buffer analyses demonstrates a progressive increase in green space accessibility as the service distance expands from 300 m to 800 m. The 300 m buffer represents immediate neighbourhood-level access but leaves extensive portions of Chennai underserved. The 500 m buffer provides a more balanced representation of park accessibility and aligns closely with commonly accepted urban planning standards

offers the highest spatial coverage and reduces accessibility gaps across much of the city. However, even at this distance, several high-deficiency zones persist, particularly in the southern and western parts of Chennai. This pattern indicates that expanding buffer distance alone cannot eliminate green space deficiencies where parks are absent. Therefore, the findings emphasize the need for establishing additional parks and open spaces in underserved neighbourhoods rather than relying solely on increasing the service radius of existing parks. The combined analysis of buffer accessibility and the Open and Green Space Deficiency map clearly identifies priority areas for future green infrastructure development and supports evidence-based urban planning strategies aimed at mitigating urban heat island effects and improving environmental sustainability.

Open and Green Spaces Deficiency Mapping

The central portion of Chennai predominantly falls within the **moderate to high deficiency classes (1.32–2.09)**, indicating that these highly urbanized areas have relatively limited green space compared to the surrounding regions. The continuous urban fabric, characterized by dense residential, commercial, and transportation infrastructure, has reduced the availability of open land and vegetation, resulting in greater environmental deficiency.

Several localized **very high deficiency zones (>2.09)**, represented by the darkest blue shades, are scattered throughout the city, particularly in the south-central, southeastern, and western urban neighborhoods. These areas likely correspond to intensely developed residential or industrial zones where impervious surfaces dominate and vegetation cover is minimal. The concentration of these high-deficiency patches suggests that urban

network, creating isolated areas with limited ecological and recreational benefits.

In contrast, the **low and very low deficiency classes (≤ 1.32)** are mainly observed in the peripheral parts of the study area and around major water bodies and large vegetated patches. These locations retain comparatively better vegetation cover and open land, which contribute to lower land surface temperatures and improved environmental quality. Large lakes, wetlands, and institutional green spaces appear to function as important ecological assets that reduce local green space deficiency. The western and southwestern portions of the study area exhibit a relatively lower level of deficiency compared with the densely urbanized city core. This pattern reflects the presence of agricultural land, open spaces, and fragmented vegetation that have not yet been fully converted into built-up land. Similarly, the northern peripheral areas show isolated pockets of lower deficiency associated with remaining green landscapes.

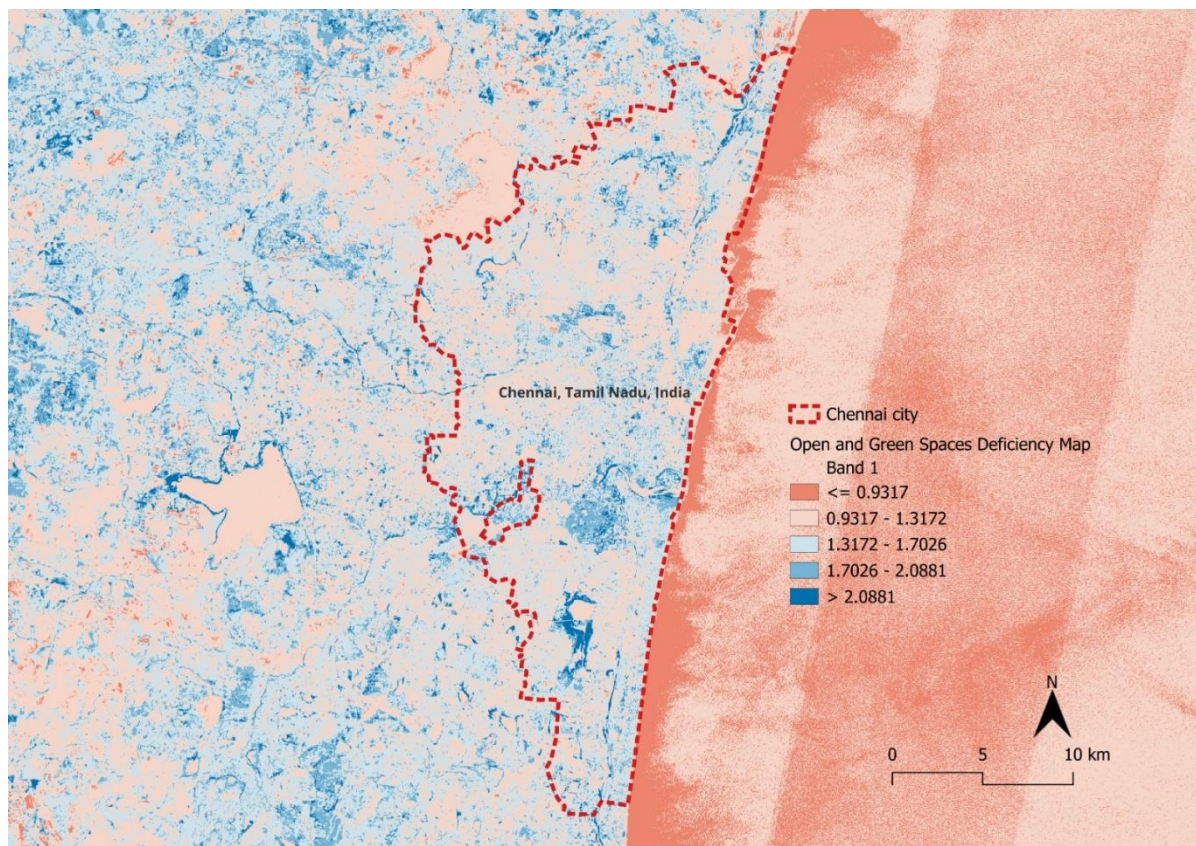


Figure 18 : Open and Green Spaces Deficiency Map

expansion has fragmented the existing green

The eastern coastal corridor presents a mixed pattern. Although the coastal influence

provides some thermal moderation, several inland coastal neighborhoods continue to display moderate to high green space deficiency due to dense urban development along the shoreline. This indicates that proximity to the sea alone does not compensate for the lack of urban vegetation and accessible green spaces. The spatial distribution of deficiency closely corresponds with the previously generated **Land Surface Temperature (LST)** and **Urban Heat Island (UHI)** maps. Areas identified as having high green space deficiency generally coincide with zones of elevated surface temperature and stronger UHI intensity, confirming the important role of vegetation in regulating the urban thermal environment. Likewise, regions with lower deficiency correspond to higher NDVI values, lower NDBI values, and greater water availability, demonstrating the combined influence of vegetation and water bodies on urban environmental conditions.

The Figure 18 map also indicates that green and open spaces are **unevenly distributed** across Chennai rather than forming a continuous network. Large green spaces are concentrated in only a few locations, leaving many densely populated neighborhoods dependent on limited or fragmented vegetation. This uneven spatial distribution suggests disparities in access to environmental amenities and highlights neighborhoods that may require priority intervention through urban greening initiatives.

Conclusion

The present study successfully integrated remote sensing and GIS techniques to evaluate the spatial relationship between urban green spaces, land surface temperature (LST), Urban Heat Island (UHI) intensity, and park accessibility in Chennai. Multi-criteria spatial analysis using NDVI, NDBI, NDWI, LST, and UHI datasets revealed significant spatial variability in environmental conditions across the study area. The results demonstrate that vegetation cover, built-up land, and water bodies are the principal factors influencing the city's thermal

environment and the distribution of open and green spaces.

The NDVI analysis indicated that vegetation is unevenly distributed throughout Chennai, with comparatively higher vegetation cover occurring around lakes, wetlands, institutional campuses, and the urban fringe, while the densely developed central and southern parts of the city exhibit relatively low vegetation density. Conversely, the NDBI analysis identified a concentration of built-up land in the urban core and rapidly expanding suburban areas, reflecting the influence of continuous urbanization. NDWI results highlighted the localized cooling effects of water bodies, particularly around major lakes and coastal areas, where higher moisture availability contributes to lower surface temperatures.

The Land Surface Temperature analysis showed a clear spatial variation, with elevated temperatures occurring primarily within highly urbanized and densely built-up regions. The Urban Heat Island analysis further confirmed that these areas experience stronger heat accumulation due to reduced vegetation, extensive impervious surfaces, and limited natural cooling mechanisms. Areas characterized by high NDVI and NDWI generally corresponded with lower LST and weaker UHI intensity, whereas areas with high NDBI exhibited elevated temperatures and stronger Urban Heat Island effects. These spatial relationships indicate a strong inverse association between vegetation cover and surface temperature and a positive association between built-up intensity and thermal stress.

The weighted overlay analysis combining NDVI, NDBI, NDWI, LST, and UHI produced the Open and Green Spaces Deficiency Map, which identified distinct spatial patterns of environmental deficiency. Most of the Chennai metropolitan area falls within the moderate deficiency category, while localized high and very high deficiency zones are concentrated in densely urbanized neighborhoods where vegetation is fragmented and open spaces are scarce. Lower deficiency values are mainly

associated with peripheral green areas, water bodies, and large institutional landscapes that continue to provide ecological and thermal benefits.

The hotspot and buffer analyses of urban parks further demonstrated that access to green spaces is spatially uneven. The 300 m buffer analysis showed that only a limited proportion of the urban population has immediate access to parks, while the 500 m and 800 m buffers expanded coverage but still revealed several underserved neighborhoods, particularly in rapidly urbanizing residential and industrial areas. These accessibility patterns correspond closely with the high-deficiency zones identified in the weighted overlay analysis, indicating that neighborhoods experiencing greater environmental stress also tend to have lower accessibility to public green spaces.

Overall, the integrated spatial analysis demonstrates that increasing urbanization has reduced vegetation cover, increased built-up land, intensified surface temperatures, and contributed to the development of Urban Heat Islands across Chennai. The results provide strong evidence that inadequate distribution of green and open spaces is directly associated with increased thermal stress and reduced environmental quality. The identified high-deficiency areas should therefore be prioritized for urban greening initiatives, including the development of neighborhood parks, urban forests, green corridors, roadside plantations, and the protection of existing water bodies and natural ecosystems.

The study confirms that the integration of remote sensing indices, thermal indicators, GIS-based multi-criteria analysis, and park accessibility assessment provides an effective framework for identifying environmentally vulnerable urban areas and supporting sustainable urban planning. The findings can assist planners and policymakers in prioritizing green infrastructure investments to mitigate Urban Heat Island effects, improve climate resilience, and enhance the overall livability of Chennai.

Overall Research Outcome

The study concludes that the spatial distribution of green and open spaces in Chennai is uneven and insufficient to effectively counteract the impacts of rapid urbanization and Urban Heat Island formation. The combined evidence from NDVI, NDBI, NDWI, LST, UHI, hotspot analysis, park accessibility, and the Green Space Deficiency Index consistently indicates that areas with lower vegetation cover, higher built-up intensity, and limited access to parks experience the greatest environmental stress. Consequently, expanding urban green infrastructure and improving equitable access to parks should be considered a priority for sustainable urban development and climate adaptation in Chennai.

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Data availability :

Data will be made available on request.

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