Urban Parks and Their Cooling Potential: Evaluating How Park Characteristics Affects Land Surface Temperature

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Abstract

Urbanization significantly alters city landscapes, exacerbating the Urban Heat Island (UHI) effect, where cities experience significantly higher temperatures compared to their rural surroundings due to impervious surfaces and heat emissions. As cities expand, mitigating UHI and improving urban thermal comfort becomes critical. Urban parks play a key role in cooling cities, typically being 1–2°C cooler than surrounding areas, with temperature differences of up to 7°C. This study evaluates the cooling potential of seven urban parks in Kolkata, India, using Landsat 8 for Land Surface Temperature (LST) and Sentinel 2 for vegetation mapping. The study assessed Park Cooling Intensity (PCI) along with related metrics such as Cooling Range & Temperature Drop Amplitude.It also examines how internal park characteristics, including vegetation density, impervious surface fraction, water bodies, & tree height, influence LST. Results show PCI ranges from 0.75-6.84°C, with an average temperature reduction of 2.87°C in park surroundings. Factors like tree height and water bodies enhance PCI, while a negative correlation exists between PCI and park area, suggesting that park size alone does not maximize cooling benefits. Vegetation density and water features are crucial for optimizing PCI, indicating that well-designed park features are more important than park size for UHI mitigation. These findings guide urban planners and policymakers in designing parks that maximize cooling effects, reduce UHI, and enhance urban climate resilience. Strategic planning of park elements can foster healthier, more sustainable cities capable of adapting to climate change and rapid urbanization.

1. Introduction

Urbanization has significantly transformed city environment worldwide, often leading to the intensification of the Urban Heat Island (UHI) effect (Thompson 1981). UHI refers to the phenomenon where urban areas exhibit higher temperatures compared to their rural surroundings, primarily due to human activities and the altered landscape (Yang et al., 2016). As cities grow, natural surfaces like soil, grasslands, and forests are replaced with impervious materials such as concrete, asphalt, and buildings. These materials have high heat-retention capacities, absorbing heat during the day and slowly releasing it at night, which prevents cities from cooling down (Bouyer et al., 2011). Additionally, anthropogenic heat sources like vehicles, industries, air conditioning units, and other energy-consuming activities further exacerbate the UHI effect (Masson 2006; Etheridge and Ford 2008). The combination of these factors results in a hotter urban environment, which has broad implications for public health, energy consumption, and overall urban sustainability.

The UHI effect raises concerns, especially for urban residents' thermal comfort. The higher temperatures associated with UHI can lead to increased heat-related illnesses, particularly during heatwaves,with vulnerable populations such as the elderly and those with pre-existing conditions being most at risk (Voogt 2004). Furthermore, higher temperatures lead to increased energy demands, as more air conditioning is required to maintain indoor comfort, which in turn raises energy costs and increases greenhouse gas emissions. This feedback loop further exacerbates the environmental challenges posed by urbanization (Gupta et al., 2024). As cities continue to expand and densify, the need to develop effective strategies for mitigating UHI and improving urban thermal comfort has become increasingly urgent.

One of the most promising strategies for reducing UHI is the integration of urban green spaces, particularly parks, into city planning (Gupta et al., 2024). Research has shown that urban parks serve as natural cooling elements, creating cooler microclimates within cities that can help reduce the overall temperature of urban areas and improve urban thermal comfort. Studies by Bowler et al. (2010) and Yan et al. (2018) demonstrate that parks typically exhibit cooler temperatures than surrounding built-up areas, primarily due to the evapotranspiration and shading provided by vegetation.This cooling effect is often referred to as Park Cooling Intensity (PCI), which represents the temperature difference between the park and its surrounding urban environment (Pramanik&Punia, 2019). Research has shown that urban parks can be 1–2°C cooler than the surrounding areas, and in some cases, the temperature difference can reach up to 7°C (Du et al., 2017). These temperature differences occur because parks typically have more vegetation and fewer impervious surfaces, which allows for greater evapotranspiration and shading—both of which contribute to cooling.

In addition to cooling the interior of parks, these spaces can influence the temperatures of nearby urban areas. The extent of this cooling effect, termed the Cooling Range (CR), varies based on the characteristics of each park (Pramanik&Punia, 2019). Factors such as park size, vegetation density, water bodies, and the amount of impervious surface influence a park's cooling effectiveness (Zhang et al., 2024; Zhibin et al., 2015). For instance, parks with water bodies tend to have a stronger cooling impact due to the thermal properties of water, while parks with dense tree cover provide significant shading and enhance evapotranspiration (Gupta et al., 2024).

The primary objectives of this study are twofold. First, it seeks

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to evaluate the influence of urban parks on Land Surface Temperature (LST), providing a clearer understanding of how parks contribute to cooling in urban environments. Second, the study aims to analyze the relationship between PCI and various park characteristics, such as vegetation density, tree height, water bodies, and impervious surfaces. By examining these relationships, this research will offer valuable insights into how specific park features affect their cooling potential, guiding urban planners and policymakers in designing parks that maximize their ability to reduce temperatures and mitigate the UHI effect.

2. Study Area

The study area comprises urban parks in Kolkata, India, located at 22.5726° N latitude and 88.3639° E longitude (Figure 1). As one of the most densely populated cities in India, Kolkata is home to over 4.5 million residents, resulting in a high demand for urban space and infrastructure. Rapid urbanization has significantly contributed to the UHI effect, resulting in elevated temperatures compared to surrounding rural areas (Halder et al., 2021). The city features a diverse mix of residential, commercial, and industrial developments, which, coupled with its tropical wet and dry climate—characterized by a monsoon season from June to September and mild winters—exacerbates thermal discomfort for residents (Dasgupta et al., 2013). Kolkata's urban landscape includes significant green spaces, most notably the Maidan, one of Asia's largest parks, which spans over 1,000 acres and serves as a vital natural cooling zone. Other important parks, such as Victoria Memorial Gardens, RabindraSarobar, and Central Park, also play crucial roles in providing greenery within the urban environment. This study focuses on seven urban parks in Kolkata, as outlined in Table 1.

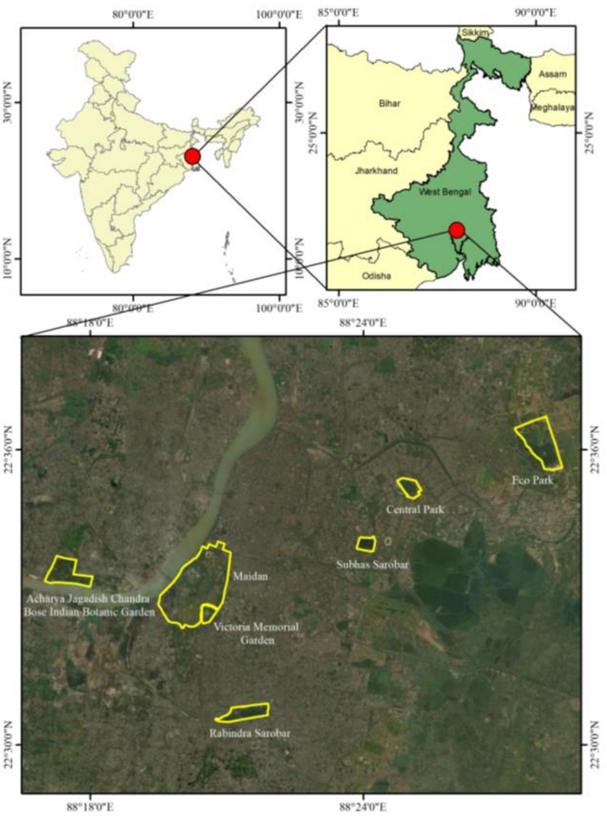

Figure 1. Study Area

Table 1. Urban Parks

Urban Parks	Location	Area (acres)
Maidan	Central Kolkata	1283
Eco Park	New Town	480
Acharya Jagadish Chandra Bose Indian Botanic Garden	Shibpur, Howrah	270
RabindraSarobar Park	South Kolkata	192
Central Park	Salt Lake	152
SubhasSarobar Park	South Kolkata	73
Victoria Memorial Gardens	Central Kolkata	64

3. Material & Method

3.1 Dataset used

The study uses Sentinel 2 image for land use land cover (LULC) classificationand Landsat 8 for LST computation. The operational land imager (OLI) bands are used for emissivity calculation and for LST, the thermal infrared (TIR) band (Band 10) at 10.60-11.19 µm wavelength is used. And tree canopy height is obtained from theGlobal Canopy Height map (Meta, 2024) (Table 2).

Table 2. Detail of Datasets used

Data	Resolution (m)	Source
Sentinel 2	10	Google Earth Engine
Landsat 8	30	Google Earth Engine
Tree Height	1	Meta Global Canopy Height Model

3.2 Methodology

This research adopts a two-stage methodology. The first stage involves calculating PCI and other cooling metrics such as Cooling Range (CR) and Temperature Drop Amplitude (TA). The second stage focuses on analyzing the correlation between the physical characteristics of the parks and their cooling performance.

3.2.1 Data Processing: This sub-section outlines the preparation of the key input variables for the study (Figure 2).

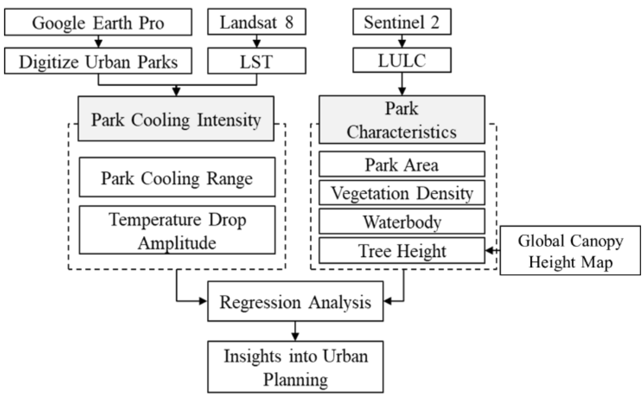

Figure 2. Methodology flowchart for the study

(a) LULCClassification: Sentinel-2 satellite imagery was utilized to generate the LULC map, with a random forest classifierin Google Earth Engine. This approach enabled the identification of multiple classes, including built-up areas, sparse vegetation, moderate vegetation, dense vegetation, and water bodies. The accuracy of the classification was assessed using a confusion matrix.

(b) Urban Park Delineation: Google Earth Pro was used to manually digitize the boundaries of urban parks in the study area. These delineated polygons served as the basis for analyzing park-specific characteristics and their thermal performance.

(c)LST Computation: Landsat 8 TIRS bands were processed using the single-channel method to compute LST (Cristobal et al., 2018). First, the digital numbers (DN) of the thermal band were converted to spectral radiance using the radiometric rescaling factors provided in the metadata. The spectral radiance was then transformed into brightness temperature using the inverse of Planck's law, accounting for sensor calibration constants. To correct for surface characteristics, land surface emissivity (LSE) was estimated based on the Normalized Difference Vegetation Index (NDVI) method. Finally, the LST was computed by applying an emissivity correction to the brightness temperature, yielding the surface temperature values.

(d) Tree Height Extraction: For the study area in Kolkata, tree canopy height was extracted using the Global Canopy Height Maps dataset, which offers 1m resolution data on canopy heights globally from 2009 to 2020, with a focus on data from 2018 to 2020. Developed by Meta and the World Resources Institute, the dataset utilizes advanced AI models, such as DiNOv2, achieving a mean absolute error of 2.8 meters (Tolan et al., 2024). This high-resolution data enabled accurate mapping of tree canopy heights across Kolkata, providing insights into vegetation structure crucial for urban environmental quality analysisand UHI mitigation.

3.2.2 Urban Park Cooling Metrics: The cooling performance of urban parks was assessed using key indicators, including PCI, CR, and TA. For a detailed analysis, a 600-meter buffer zone was established around each park, divided into 30 segments at 20-meter intervals (Pramanik&Punia 2019). This allowed for precise calculations of the temperature variations and cooling metrics.

(a) Park Cooling Intensity (PCI): The PCIiscommonly assessed by comparing the temperature within a park to that of its surroundings (Cao et al., 2010). In this study, PCI is defined as the difference in LST between the park's interior and its surrounding area, and is calculated using Equation 1:

$$PCI = T_u - T_p \qquad \text{Equation 1}$$

Where, T_u represents the temperature outside the park and T_p represents the temperature inside the park.This metric quantifies the extent of temperature reduction inside the park relative to its urban surroundings, serving as the primary indicator of the park's cooling capacity.

(b)Cooling Range (CR): ParkCR measures the distance from the park's boundary within which significant cooling effects extend into the surrounding urban area. The cooling range is determined by analyzing the temperature gradient from the park's edge, with the first turning point on the temperature curve marking the boundary of the cooling effect (Pramanik&Punia 2019).

(c) Temperature Drop Amplitude (TA):TA measures the maximum temperature difference between the park's interior and the temperature at the first turning point outside the park, indicating the peak cooling potential (Pramanik&Punia 2019).

3.2.3 Statistical Correlation Analysis:A regression analysis was performed to investigate the relationship between various park attributes and their cooling effects. The independent variables, such as park area, vegetation density, presence of water bodies, and tree height, were regressed against the dependent variables, such as PCI, CR, and TA. This statistical method allowed for the identification of critical park characteristics that significantly contribute to enhancing cooling efficiency.

4. Results & Discussion

4.1 Overview of Input Data

4.1.1 LULCAnalysis: The LULC map for Kolkata illustrates a mix of built-up areas, vegetation, and water bodies (Figure 3). Built-up regions, which constitute 28.67% of the total area, are predominantly located in the central and northern parts of the city, exacerbating the UHI effect. The area statistics indicate that sparse vegetation, covering 29.61%, is primarily found along the outskirts and interspersed within urban structures. Moderate vegetation occupies 17.38% of the area, while dense vegetation, accounting for 21.99%, is concentrated in a few urban pockets and along the peripheries of the city. Water bodies, including the Hooghly River, a major water body running along the city's western edge, and smaller scattered lakes, make up 2.34% of the landscape, providing critical natural cooling corridors and enhancing the microclimate (Figure 4).

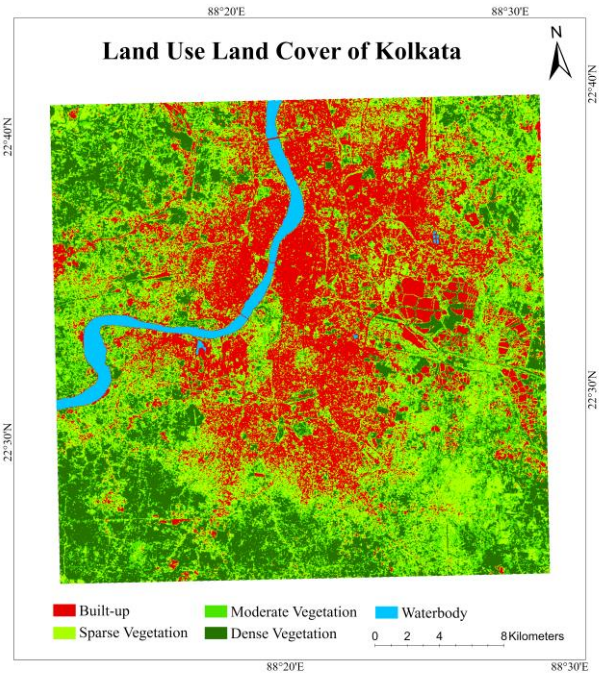

Figure 3. Land Use Land Cover for Kolkata

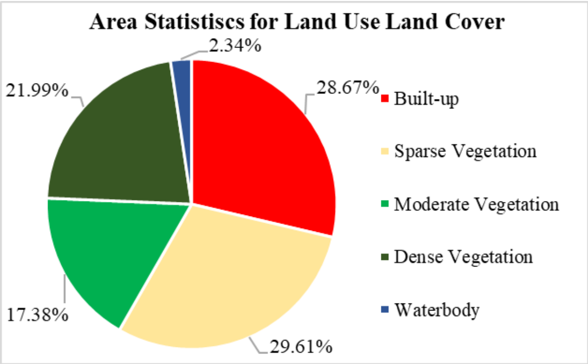

Figure 4. Area statistics for Kolkata's Land Use Land Cover

The LULC obtained an overall accuracy of 89.67% with a kappa of 0.88. This LULC classification offers a detailed perspective on Kolkata's urban structure, crucial for analyzing its thermal environment and the cooling influence of both urban parks and water bodies.

4.1.2 Land Surface Temperature: The LST map for Kolkata reveals significant thermal variations across the city (Figure 5).

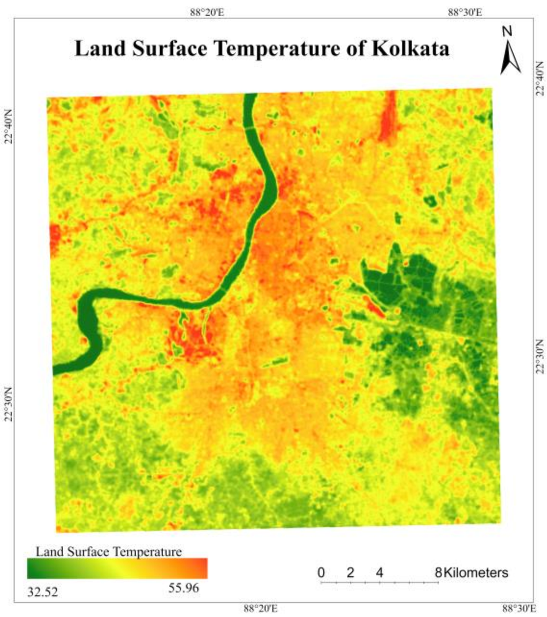

Figure 5. Land Surface Temperature for Kolkata

The LST analysis shows a maximum temperature of 55.96°C and a minimum of 32.52°C, with a mean LST of 42.35°C and a standard deviation of 3.48°C. This indicates a generally consistent temperature distribution across the area, though certain urban hotspots are evident. The elevated temperatures are largely a result of extensive built-up environments and a scarcity of green spaces in densely populated zones. The significant temperature variation underscores the critical need for strategic urban planning and the incorporation of green infrastructure to mitigate UHI.

4.2 Characteristics of Urban Parks

The urban parks in this study exhibit diverse characteristics, each contributing uniquely to their cooling potential. These parks vary significantly in size, vegetation density, tree height, and the presence of water bodies.

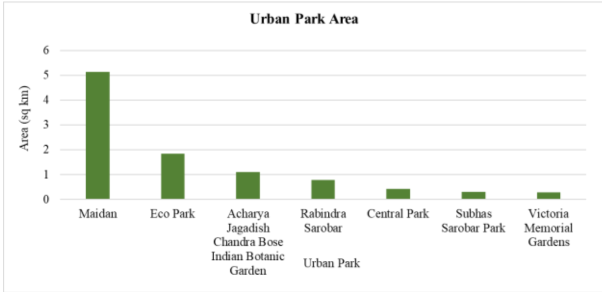

Figure 6. Area percentage of urban parks in Kolkata

The urban parks in Kolkata vary in size, with the Maidan being the largest, followed by Eco Park, Acharya Jagadish Chandra Bose Indian Botanic Garden, RabindraSarobar, Central Park, Subhas Park, and Victoria Memorial Gardens, as shown in Figure 6 and Table 1.

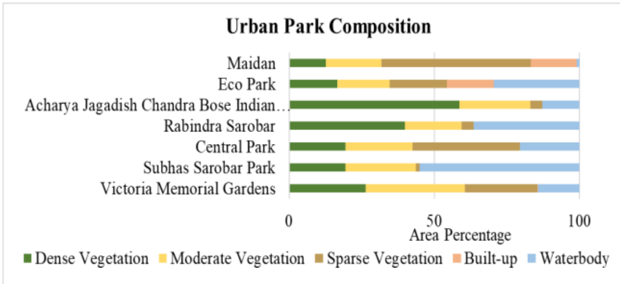

Figure 7. Urban Park composition in Kolkata

The composition of Kolkata's urban parks, as shown in Figure 7, reveals a diverse mix of vegetation, built-up areas, and water bodies. Maidan, the largest park, covers 5.13 sq km, with over 50% of its area occupied by sparse vegetation, offering a vast but less dense green space. The Acharya Jagadish Chandra Bose Indian Botanic Garden spans 1.11 sq km, where dense vegetation dominates 58% of the area. SubhasSarobar Park, although smaller at 0.30 sq km, features a waterbody that covers 55% of its area, complemented by 19% dense vegetation (Figure 7).

Table 3. Mean tree height in Urban Parks in Kolkata

Parks	Mean Tree Height (m)
Maidan	3.21
Eco Park	0.75
Acharya Jagadish Chandra Bose Indian Botanic Garden	10.17
RabindraSarobar	4.57
Central Park	4.08
SubhasSarobar Park	3.13
Victoria Memorial Gardens	4.00

The tree canopy height distribution across the parks varies significantly, influencing their cooling potential. The Acharya Jagadish Chandra Bose Indian Botanic Garden stands out with the highest mean tree height of 10.17 meters, indicating a robust vertical structure of vegetation. Followed by RabindraSarobar with a mean height of 4.57 meters, while Central Park and Victoria Memorial Gardens show moderate tree heights of 4.08 and 4.00 meters, respectively. Maidan, despite its large size, has a relatively low mean tree height of 3.21 meters, and Eco Park has the lowest, at just 0.75 meters. These differences in tree height play a crucial role in the parks' shading and cooling effects (Table 3).

4.2.1 Park Typology: The parks were classified into three distinct categories based on their characteristics for streamlined analysis:

Type A: Parks with a significant proportion of waterbodies, including SubhasSarobar, RabindraSarobar, and Eco Park.

Type B: Parks featuring dense vegetation and tree heights exceeding 4 meters, such as the Botanic Garden, Central Park, and Victoria Memorial Gardens.

Type C: Parks dominated by sparse vegetation and tree heights below 4 meters, represented by Maidan.

This categorization facilitates a clearer understanding of how varying park features affect LST and cooling potential.

4.3 Park Cooling Intensity

PCI was assessed using temperature profiles around each park. The graph includes vertical lines indicating the CR for each park (Figure 8).

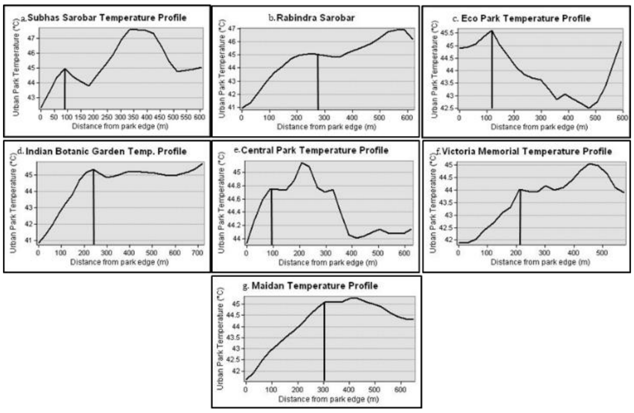

Figure 8. Temperature Profile for Urban Parks in Kolkata, (a) SubhasSarobar, (b) RabindraSarobar, (c) Eco park, (d) Acharya Jagadish Chandra Bose Indian Botanic Garden, (e) Central Park, (f) Victoria Memorial, (g) Maidan

The PCI values range from 0.34°C to 6.84°C, with an average of 2.87°C, demonstrating that urban parks can lower temperatures by 0.34°C to 6.84°C in surrounding areas. CR extends from 85 meters to 305 meters, averaging 190 meters. Temperature Drop Amplitude (TA) shows significant variation, ranging from 0.46°C to 5.84°C, with an average of 3.48°C.Table 4 summarizes key cooling metrics for the parks.

Type A: Parks with a high proportion of waterbodies

- SubhasSarobar Park: Exhibits the highest PCI of 6.84°C, indicating its significant cooling effect on surrounding areas. The park’s waterbody, which occupies 55% of its area, plays a crucial role in temperature regulation, demonstrating the importance of waterbody in urban parks.
- RabindraSarobar: This park also shows substantial cooling potential with a PCI of 5.13°C. The presence of water bodies and dense vegetation contributes to its ability to mitigate urban heat effectively.
- Eco Park: With a PCI of 1.66°C, Eco Park reflects a moderate cooling effect. Although it has a lower proportion of water bodies compared to SubhasSarobar and RabindraSarobar, its design integrates water features that aid in cooling the surrounding environment.

Type B: Parks with dense vegetation and tree heights exceeding 4 meters

- Acharya Jagadish Chandra Bose Indian Botanic Garden: While the PCI is relatively low at 0.75°C, this park features a high proportion of dense vegetation (58%) and the tallest mean tree height (10.17 m), contributing to biodiversity and ecological balance rather than immediate cooling effects.
- Central Park: Exhibiting a PCI of 2.00°C, this park benefits from a good mix of vegetation and tree cover. Although the cooling potential is moderate, its tree height and density offer shade and contribute to the overall cooling effect.
- Victoria Memorial Gardens: With a PCI of 3.38°C, this park combines moderate vegetation with built-up areas. The cooling effect is notable but influenced by its urban surroundings.

Table 4. Park Cooling Intensity, Cooling Range and Temperature Drop Amplitude for Urban Parks in Kolkata

Urban Parks	Temp. Inside (°C)	Temp. Outside (°C)	Park Cooling Intensity (°C)	Cooling Range (m)	Temperature Amplitude
Maidan	44.64	44.98	0.34	305.00	0.46
Eco Park	41.13	42.79	1.66	120.00	4.47
Acharya Jagadish Chandra Bose Indian Botanic Garden	40.48	41.23	0.75	245.00	4.82
Rabindra Sarobar	39.85	44.98	5.13	280.00	5.15
Central Park	42.90	44.90	2.00	90.00	1.88
Subhas Sarobar Park	39.16	46.00	6.84	85.00	5.84
Victoria Memorial Gardens	42.28	45.66	3.38	205.00	1.72

Type C: Parks with sparse vegetation and tree heights below 4 meters

- Maidan: Despite being the largest park (5.13 sq km), it has the lowest PCI at 0.34°C. The predominance of sparse vegetation limits its cooling potential, although its extensive area may still influence temperatures over a broader range.

The analysis reveals that parks with a high proportion of water bodies (Type A) generally exhibit higher PCI, effectively mitigating UHI. In contrast, parks characterized by dense vegetation (Type B) show moderate cooling effects, influenced by tree height and density. Parks with sparse vegetation (Type C), such as Maidan, tend to have the least cooling potential, highlighting the importance of vegetation and water features in urban park design for climate mitigation.

4.4 Correlation Between Park Characteristics, LST, and PCI

4.4.1 Relationship Between Park Characteristics and LST: The analysis of the relationship between park characteristics and LST reveals significant insights into the cooling effects of different vegetation types and park features. The coefficient of determination (R^2) values demonstrate the extent to which each characteristic contributes to reducing LST. Water bodies exhibit a negative R^2 value of 0.68, highlighting their critical role in cooling urban environments. These features not only provide shade but also promote evaporation, significantly lowering surrounding temperatures. Tree height has a R^2 value of 0.52, indicating a moderate relationship with LST reduction. Taller trees are particularly effective in cooling the environment, as they provide substantial shade and enhance the process of evapotranspiration, contributing to lower surface temperatures. In contrast, dense vegetation has a low R^2 value of 0.27, suggesting a less pronounced impact on LST compared to other characteristics. While it does contribute to cooling, its effectiveness may be limited by factors such as the species present and the overall park design.

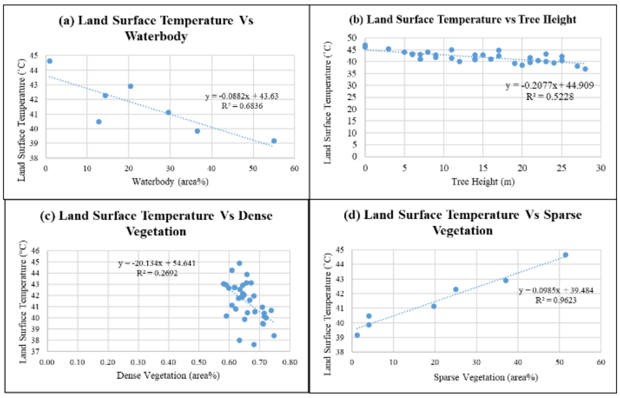

Figure 9. Correlation between Park Characteristics and LST, (a) waterbody, (b) tree height, (c) dense vegetation, and (d) sparse vegetation.

Notably, sparse vegetation shows the highest positive correlation with LST, with R^2 value of 0.96. This indicates that areas with sparse vegetation do not have a cooling effect on their surroundings; instead, as the amount of sparse vegetation increases, the LST also rises. This can be attributed to more sunlight reaching the ground, which elevates surface temperatures. Furthermore, sparse vegetation has a limited capacity for evapotranspiration, leading to decreased cooling. Additionally, it may create microclimates that trap heat, particularly in urban environments where heat-retaining structures amplify the UHI.

Specific features within urban parks, particularly sparse vegetation and water bodies, have a significant impact on reducing LST. Taller trees enhance the cooling effect by providing shade and facilitating evapotranspiration. This highlights the importance of incorporating these elements in urban park design to mitigate UHI. Understanding these relationships can inform urban planning and the development of green spaces that effectively address the challenges posed by rising temperatures in urban environments.

4.4.2 Relationship Between Park Characteristics and PCI: The analysis of the relationship between park characteristics and PCI reveals several critical insights into how specific park characteristics influence PCI in urban areas. One of the key observations is that urban park areas, although intuitively expected to improve cooling, show a negative correlation with PCI (R^2=0.35). This suggests that larger parks may not always translate into greater cooling, potentially due to the presence of non-vegetative elements like built-up areas or sparse vegetation, which can counteract cooling effects. The weak positive correlation of dense vegetation (R^2=0.0028) with PCI further emphasizes that simply having vegetation may not guarantee effective cooling; the type, health, and arrangement of vegetation within the park matter.

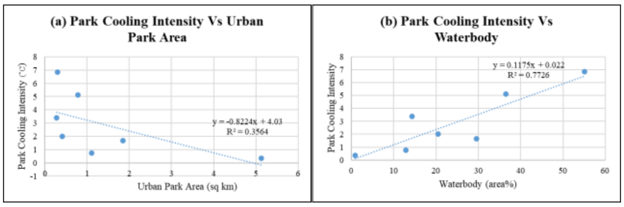

Figure 10. Correlation between Park Cooling Intensity and Park Characteristics, (a) waterbody, and (b) park area.

Water bodies, on the other hand, emerge as a major contributor to cooling, with a strong positive correlation (R^2=0.77) to PCI. This underscores the role of water features in enhancing the cooling potential of parks through evaporation and heat absorption. Conversely, sparse vegetation (R^2=0.38) and built-up areas (R^2=0.28) negatively correlate with PCI, suggesting that such elements not only reduce the park's ability to cool but can also trap and retain heat, exacerbating local warming. This aligns with broader urban planning challenges, where the balance of natural and built elements must be carefully managed to maximize the cooling benefits of green spaces.

The overall findings suggest that the quality and type of park features—particularly the presence of water bodies and dense vegetation—are more important than park size alone in determining cooling intensity. Therefore, urban park designs that prioritize the integration of water features and healthy, well-maintained vegetation while minimizing built-up and sparsely vegetated areas can more effectively address urban heat issues.

5. Conclusion

This study investigates the relationship between urban park characteristics and their impact on LST and PCI. By examining key features such as tree height, water bodies, and park size, the analysis aims to understand how different park elements influence cooling effects in urban environments. The findings reveal that certain features, like taller trees and water bodies, play a crucial role in enhancing cooling, while park size alone does not guarantee higher PCI. Taller trees show a strong negative correlation with LST, reducing temperatures through shading and evapotranspiration. Water bodies also have a significant positive impact on PCI, contributing to cooling by promoting evaporation and lowering surrounding temperatures. However, larger park areas do not inherently offer greater cooling benefits; the presence of essential features such as dense vegetation and water bodies is key. The negative correlation between park size and PCI suggests that park design, rather than size, plays a more critical role in mitigating urban heat. In conclusion, effective urban park design must prioritize the inclusion of cooling elements like tall trees, vegetation, and water bodies. By focusing on these features, urban planners can enhance the cooling potential of green spaces and better mitigate the UHI effect, creating more comfortable urban environments.

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