

RESEARCH ARTICLE

Urban cooling optimization in Ahmedabad: Defining optimal radius for the thermal performance of water bodies and green spaces

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ABSTRACT

Urban water bodies and vegetation are integral components of urban landscapes. They contribute to thermal comfort, providing essential cooling effects that alleviate the impacts of rapid urbanization. The study emphasizes the importance of planning and performance assessment of these landscapes to achieve maximum cooling and extend their influence effectively. It is well-documented that urban vegetation and water bodies reduce local temperatures which can be evaluated through various landscape indices suggesting that the shape and configuration of these areas greatly impact their cooling capabilities and influence. To explore this further, a spatio-temporal analysis focusing on Land Surface Temperature (LST) is conducted by using high-resolution satellite imagery in 39 water bodies and 130 dense vegetation sites in Ahmedabad, Gujarat to identify thermal patterns and assess the cooling performance of landscape features. The analysis aimed to understand the relationship between temperature changes and the radius of landscape sites leading to the identification of the Radius of Saturation (R_{sat}) which is the maximum distance around a water body or green space where its cooling effect is most effective. The results indicated that the R_{sat} is 150 meters for water bodies and 130 meters for dense vegetation. These radii mark the points at which further increases in size do not significantly enhance the cooling effect, signifying the saturation point for thermal influence.

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INTRODUCTION

Urban water bodies and vegetation are integral components of city landscapes, playing a crucial role in regulating urban microclimates by acting as natural heat sinks. Their presence significantly contributes to thermal comfort and ecological balance, particularly in densely built environments affected by the Urban Heat Island (UHI) effect. To fully harness their cooling potential, it is essential to evaluate the spatial performance of these elements and integrate them effectively within the urban fabric through informed planning.

Prior research has demonstrated that the ability of green and blue spaces to lower local temperatures is influenced not only by their presence but also by their shape, size, and

configuration. Various landscape indices—such as the Landscape Shape Index and Patch Density Index—have been developed to quantitatively assess these spatial characteristics. These indices help in understanding how geometric attributes and spatial patterns of vegetation and water bodies affect their cooling performance and the extent of their influence.

To further explore these dynamics, this study adopts a spatio-temporal analytical approach that utilizes Land Surface Temperature (LST) as a key indicator. This approach enables the evaluation of thermal variations across different seasons and spatial configurations, offering deeper insight into the performance of landscape features in urban settings.

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Central to this investigation is the concept of the Radius of Saturation (R_{sat}), which refers to the maximum effective distance from a landscape feature within which its cooling impact is significant. Beyond this threshold, any increase in size yields diminishing thermal benefits. By identifying the R_{sat} for various landscape elements, planners can optimize land use efficiency while maximizing thermal comfort. In the context of this study, Ahmedabad's climatic conditions offer a representative basis for assessing R_{sat} values and guiding climate-sensitive urban design.

LITERATURE REVIEW

Urban Landscapes & Their Effect

Urban blue green spaces including water bodies and green spaces play an essential role as nature-based solutions for the eradication of urban heat island and development of urban sustainability. The studies have shown that these spaces are able to significantly lower surrounding air temperatures and that the amount of cooling depends on the size, type and configuration of the space. One study found that water bodies particularly exhibit strong cooling effect, such as 3.04°C decrease in daily average air temperature [1] while urban parks decreased by 0.57°C. Water bodies can also serve as cooling bodies, with the cooling effect extending up to 2500 meters in to urban blocks, and maximum cooling by 2°C in summer [2]. Water bodies were observed to influence land surface temperature (LST) up to 350 meters [3].

In addition, green spaces, particularly urban parks, offer large amount of cooling effects. Whether parks cover between 1.55 and 13.58 hectares, vegetation is dense or there are water bodies nearby, results indicate that park temperatures can lower up to 8.28°C [4]. On the other hand, at the block scale the scale of the temperature mitigation varies from 0.7–2.7°C, at the neighborhood scale from 1.1–2.9°C and at the city scale from 0.5–2.2°C [5]. Specific characteristics of blue-green spaces and their urban contexts determine the optimal thermal performance radius of the spaces. For example, in fitting interval of 300 meters, it is found that urban parks offer the best cooling effect [6], with individual variations. For 28 parks in Zhengzhou, China, the park cooling distance ($L_{\Delta max}$) was averaged to be 194.02 meters [6]. Thus, these findings suggest that while there is no single optimal radius, cooling effects tend to be in the range a few hundred meters to more than 2 kilometers. Local studies are required for Ahmedabad to optimally define the cooling radius considering its particular climatic conditions and urban structure.

Urban green spaces and water bodies have significant impact on both urban landscapes and land surface temperature (LST) and urban microclimates. Previous research has indicated that green spaces are able to significantly decrease LST and that the ability of green space to do so is largely influenced by the spatial composition and vegetation density [7]. These cooling effects are contributed in part by mechanisms of evapotranspiration, shading and lower thermal storage capacity [8]. With rapid urbanization and increasing inertia into built up surfaces, urban heat island (UHI) effect becomes stronger, and affects on climate, air quality, water resources, and vegetation [9]. According to the example of Greater Manchester, U.K., the cooling of microclimates is required to mitigate UHI, such that a 10 per cent increase of urban green footprint in high density areas according to the 2080 s may lower the maximum air temperature up to 2.4 °C until 2.5 °C. However, a 10 percent decrease in green cover could lead to 7°C to 8.2°C temperature increase [10].

The surface temperature is notably affected by vegetation density and land cover which should be accounted when urban and green space planning are in consideration [11]. Evergreen trees are found to provide a better cooling effect than deciduous trees in summer [12]. Although, most of the studies in terms of urban green cooling effects are based on land use and vegetative cover, not on spatial configuration of the green inside urban environment [7]. Photosynthesis and transpiration of green plants help cooling through increasing the heat radiation absorption and sunlight reflection [13]. Thus, these cooling effects' magnitudes are dependent on spatial characteristics, vegetation composition, and external factors including wind speed and urban morphology [14]. Within the same locality, large green spaces effect larger degrees of cooling than small ones. It is found that urban LST is positively related to the area, perimeter, and shape index and negatively related to the perimeter to area ratio [15].

Due to the lack of green space in urban areas, strategic planning is demanded to make full use of cooling benefit. This research suggests that, rather than creating new, it is more effective to enhance connectivity between existing green spaces and that green spaces should be carefully considered by urban planners in size [9]. Vegetation types cool differently, depending on seasonal variation and measurement height. Green spaces also cool developers to some extent and the degree of city cooling effects varies with external factors, such as surrounding buildings and infrastructure [16].

Landscape Indices and Their Calculation Process

The urban cooling optimization via water bodies and green spaces was based on the calculation of certain landscape indices. The Cooling Capacity Index (CCI) is used broadly to inform whether green space can cool the air through evapotranspiration and shading. The methodology is derived from aerial vegetation cover, albedo, and evapotranspiration using remote sensing data [17]. Studies reported that for the daily average air temperature, cooling effect (CE) of 3.04°C, cooling intensity (CI) of 0.02, and cooling gradient (CG) of 2.99 [1], which means that water body reduces the daily average air temperature by 3.04°C. Blue-green spaces are effective based on size, form, and setting, a larger and better shaped water body being more useful in terms of surface area and continuous evaporation [18]. Parks larger than 1.55 hectares lower temperatures surrounding a park by up to 8.28°C [4]. Mono-window algorithm is used to calculate the Park Cooling Intensity (PCI) to quantify the park's cooling effects [4]. That study on Zhengzhou, China, detected an average cooling distance ($L_{\Delta max}$) of 194.02 metres [6]. The optimal value of a 300 m buffer zone for LST distance calculations is found [6], although these values are different for different parks.

Landscape index quantitatively assesses the arrangements of the land cover in and the composition and configuration within a specified area [7]. Common indices include:

- Fragmentation Indices: Measure landscape division into smaller, isolated patches (e.g., Patch Density Index, Edge Density Index).
- Diversity Indices: Assess land cover variety (e.g., Simpson's Diversity Index, Shannon's Diversity Index).
- Shape Indices: Quantify the geometric attributes of landscape features (e.g., Landscape Shape Index, Fractal Dimension).
- Connectivity Indices: Evaluate ecological connectivity and habitat continuity.

For this study, the following landscape indices were utilized:

Table 1. Landscape indices and parameters used to derive them

Index	Formula	Parameters	Reference
Landscape Shape Index (LSI)	$LSI = P / (2 * \text{sqrt}(\pi * A))$	Perimeter (P), Area (A)	[19]
Shannon's Evenness Index (SHEI)	$SHEI = H' / H'_{\text{max}}$	Shannon Diversity Index (H'), Maximum Shannon Diversity Index (H'max)	[20]
Shannon's Diversity Index (SHDI)	$SHDI = -\sum(\pi * \ln(\pi))$	Number of patch types (S), Proportion of landscape occupied by patch type (pi)	[21]
Configurational Edge Density (ED)	$ED = E / A$	Total edge length (E), Landscape area (A)	[22]
Patch Density (PD)	$PD = (N / A) * 10,000$	Number of patches (N), Landscape area (A)	[[23]

Understanding these indices helps optimize urban green space configurations, maximizing cooling effects [24]. The radius of landscape sites significantly affects their cooling performance, influencing the surrounding microclimate [13]. Research suggests an optimal cooling radius known as the Radius of Saturation (R_sat), beyond which additional cooling benefits are negligible [10]. The Radius of Saturation (R_sat) is defined as the critical threshold distance from the center of a water body or green space beyond which the cooling effect on the surrounding urban microclimate becomes negligible. Within this radius, the reduction in ambient temperature is significant; however, beyond this limit, additional spatial expansion of the landscape feature does not result in proportionate thermal benefits. This concept serves as a practical guideline for urban planners and environmental designers to determine the optimal spatial extent of green and blue infrastructure. By identifying the R_sat, it becomes possible to maximize cooling efficiency while ensuring sustainable land utilization, particularly in densely built urban environments prone to heat stress. Future studies in Ahmedabad should explore site-specific conditions to refine landscape planning strategies for optimal urban cooling.

METHODOLOGY

As shown in Figure 1, the methods used in this study will utilize a GIS and statistical regression techniques to perform systematic analysis between land surface temperature (LST) and other environmental factors. First, data from several sources, satellites imagery, environmental data, are collected on important land features: water bodies and green spaces. The data is then preprocessed and analyzed in ArcGIS, a geospatial tool that allows the mapping and visualization of such LST variations over different urban and natural landscapes. Specific sites are then mapped based on their land characteristics to infer temperature fluctuation in terms of their relationship with water bodies and vegetation. Piecewise regression analysis is used to quantify these relationships in order to understand in detail how LST is affected by different land cover type. These methodological frameworks will help understand the urban heat dynamics and will help turn to climate responsive urban planning and ecological conservation strategies.

Study Site

The study is on Ahmedabad, a city in Gujarat, India, situated in the Hot Steppe (BSh) climatic classification according to Köppen climate classification system. Ahmedabad is located in a region that receives high temperatures, but low annual rainfall and this classification implies that the climate in Ahmedabad is semi-arid. It is very important to understand the climatic conditions and the weather pattern of Ahmedabad to represent the spatio temporal analysis of land surface temperatures (LST) [25] correctly. The map given in Figure 2 shows the location of the study area, Ahmedabad, within India, providing geographical context for the research. This Figure 3 illustrates the geographical layout of Ahmedabad, marking the specific study areas selected for urban cooling analysis. The highlighted regions represent areas prone to excessive heat accumulation.

Within Ahmedabad, 130 dense vegetation sites (parks, gardens, graveyards and urban forests) are selected. Some are simply sites with at least 80 percent of their area covered by vegetation taller than 6 feet. The 39 water bodies included small ponds to large lakes. Therefore, these sites were selected to quantify how green spaces and water bodies can help cool down ambient temperatures and enhance urban thermal comfort. The elaborate examination seeks to develop effective town planning strategies to similar climatic areas.

The map shown in Figure 4 displays all the water body (WB) and dense vegetation (DV) sites analyzed in Ahmedabad, showing the spatial distribution of the study areas.

Data Collection and Assessment

For this study, the data collection and assessment of these sites had many important steps so that it can be well analyzed about the cooling effect of these water bodies (WB) and dense vegetation (DV) sites in Ahmedabad. High resolution satellite imagery of Google Earth Pro was used in mapping all 39 water bodies and 130 dense vegetation sites precisely. The form by which they were delineated were polygons using ArcGIS software, to these sites. This Figure 5 provides a visual example of a water body site in Ahmedabad that was part of the study. This Figure 6 showcases an example of a dense vegetation site in Ahmedabad that was analyzed in the research.

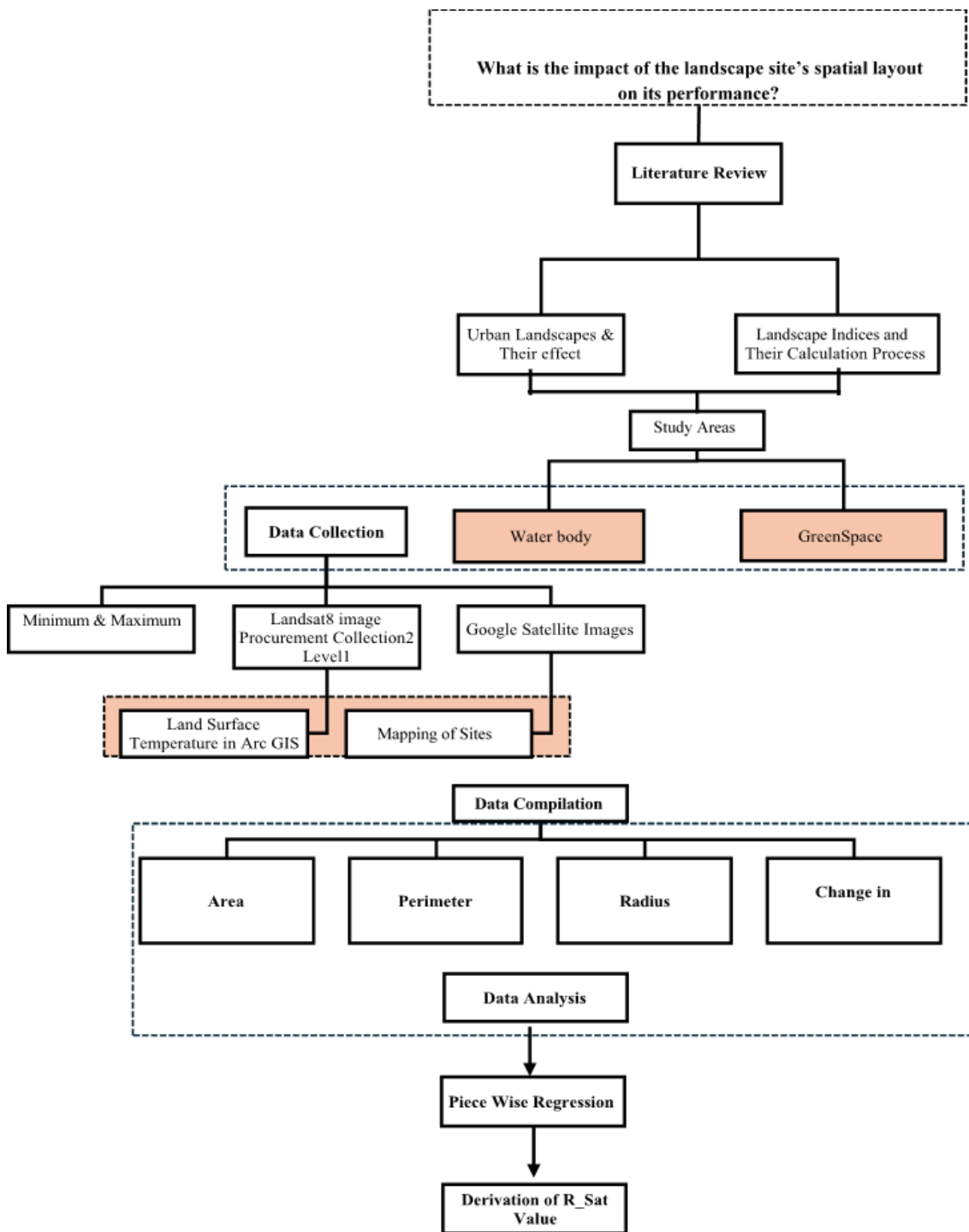


Figure 1. Detailed methodology

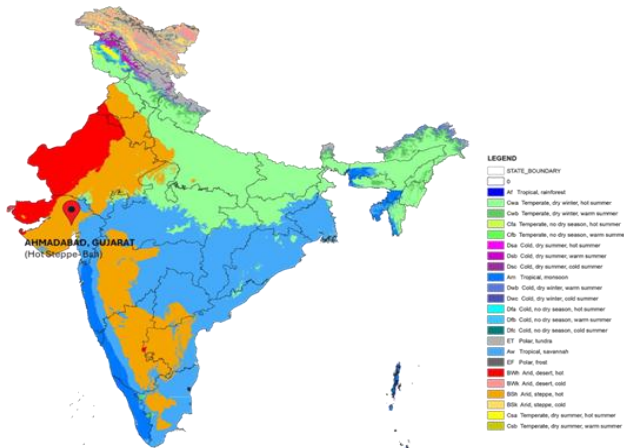


Figure 2. Map of India highlighting location of study area Ahmedabad (AMD)

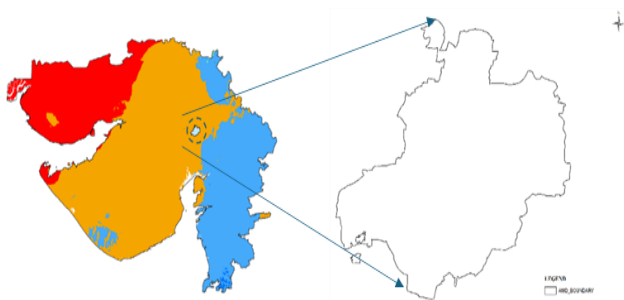


Figure 3. Map of Gujarat State highlighting location of study area AMD

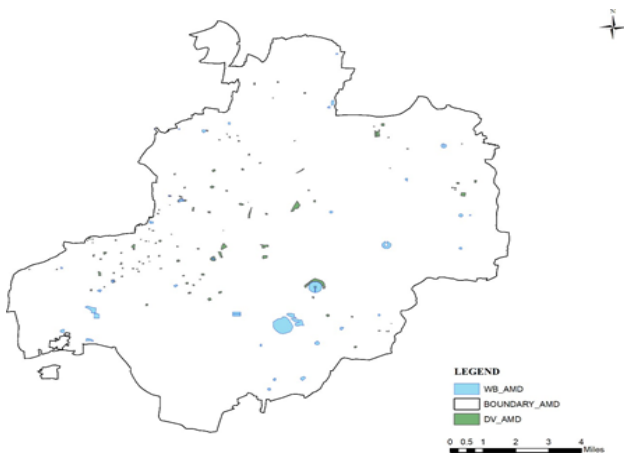


Figure 4. Mapping all water body (WB) and dense vegetation (DV) sites in AMD

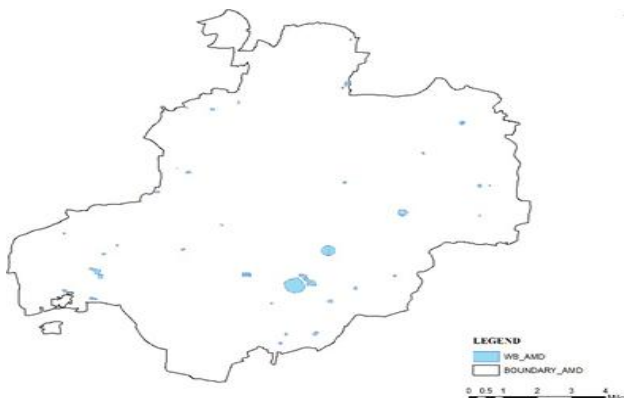


Figure 5. WB in AMD



Figure 6. DV in AMD

Land Surface Temperature (LST) Analysis

Procurement of Landsat Data: The study period was chosen to be 2022 because of the availability of satellite data as of that year. Tmax data refers to the maximum temperature data recorded over a specific period, typically on a daily, monthly, or annual basis. In climate and environmental studies like yours, it plays a critical role in understanding heat stress, urban heat islands, and thermal comfort in cities. The annual Tmax data from India Meteorological Department (IMD) libraries for Ahmedabad were used to do a comprehensive weather analysis. The peak summer period was found from March 12, 2022, to June 30, 2022, with the absolute peak of May 11, 2022. For maximum cooling effects of the landscape sites, this period became critical. For May 11, 2022, Landsat 8 data (Bands 4, 5, and 10) were procured from the USGS. However, these bands are critical to LST analysis due to the level of thermal and reflectance information contained.

LST Calculation: Landsat 8 data acquired by the procured data were processed using ArcGIS software to produce LST determined for the specified period. Different thermal patterns were observed in LST from Ahmedabad with respect to land cover types in the peak summer. Temperatures were between 27°C and 48°C in summer peak as shown in Figure 7. The highest temperatures were recorded in areas characterized by concrete-paved airstrips or runways in the northeast of the city. Dense built-up areas with tin roofs in the southwest also exhibited elevated temperatures, as did barren land patches exposed to direct sunlight. Conversely, water bodies, primarily the Sabarmati River and other large water bodies, exhibited the lowest temperatures. Dense vegetation areas maintained relatively cooler temperatures, ranging from 30°C to 33°C. Within the urban fabric, built-up areas demonstrated temperature variations based on compactness and land use, with temperatures ranging from 33°C to 43°C. This analysis helps determine how the WB and DV sites perform under extreme weather conditions, serving as a benchmark for their cooling capacities.

Extraction of LST Data: The calculated LST data were extracted for all selected sites using the "Extract by Mask" tool in ArcGIS. Subsequently, the minimum LST values for each site were determined using Zonal Spatial Analysis tools within the software, providing a focused view of the coolest areas within each landscape site as shown in Figure 8.

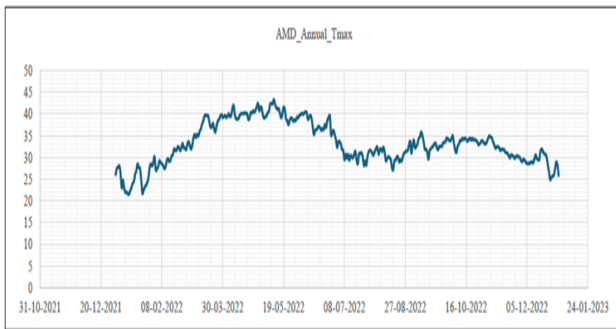


Figure 7. TmaxAMD2022

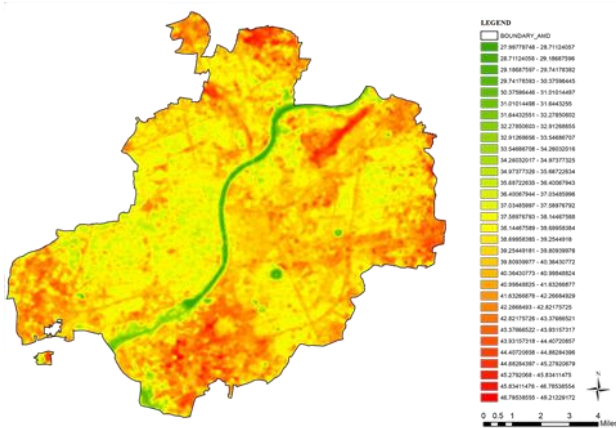


Figure 8. LST AMD

Piecewise Regression for Identifying Break Points

Data Extraction: The minimum temperature data, along with geometrical parameters (radius, area, perimeter) for all WB and DV sites, were exported in CSV format from ArcGIS.

Temperature Change Calculation: The change in temperature (ΔT), as shown in graph shown in Figure 9, was calculated by subtracting the minimum LST from the average surrounding temperature. This ΔT was then plotted, as shown in graph shown in Figure 10, with the radius of the landscape sites on the X-axis and the change in temperature on the Y-axis.

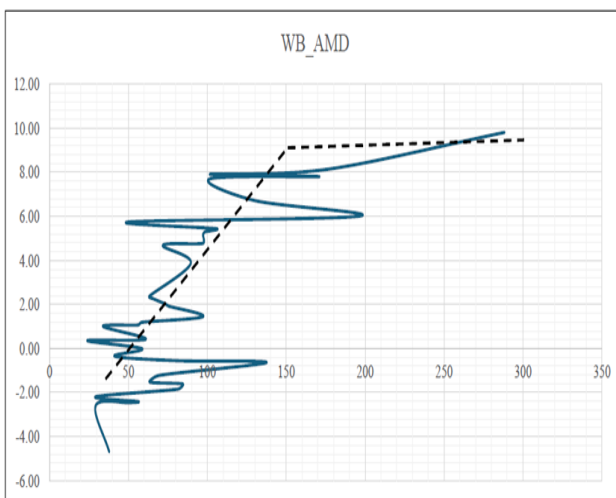


Figure 9. Radius against change in temp WB AMD

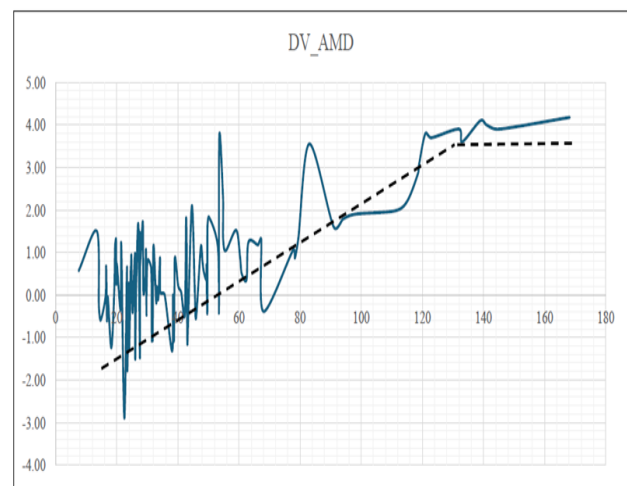


Figure 10. Radius against change in temp DV AMD

Application of AI/ML for Piecewise Regression: To analyse the relationship between the radius of the landscape sites and the change in temperature, piecewise regression was performed using AI/ML techniques in Google Colab. This advanced analysis aimed to identify the radius at which each landscape site achieves its maximum cooling potential, referred to as the "Radius of Saturation."

Algorithm for the Piecewise Regression

```

BEGIN
  // Step 1: Import Necessary Libraries
  IMPORT pandas, numpy, matplotlib.pyplot, scipy.optimize, sklearn.metrics
  IMPORT pwlf for piecewise linear fitting
  IMPORT statsmodels.api for statistical analysis
  // Step 2: Load and Preprocess Data
  READ 'Segment.csv' into DataFrame data
  x ← data['Radius'] // Independent variable
  y ← data['Temperature'] // Dependent variable
  DISPLAY data summary
  PLOT x vs. y (scatter plot)
  // Step 3: Perform Piecewise Linear Fitting
  INIT pwlf_model ← PiecewiseLinFit(x, y)
  FIT pwlf_model with 3 breakpoints
  x_test ← GENERATE evenly spaced values between min(x) and max(x)
  yHat_piecewise ← PREDICT y values using pwlf_model
  PLOT x_test vs. yHat_piecewise
  DISPLAY pwlf_model breakpoints, slopes, intercepts
  // Step 4: Train and Evaluate Linear Regression Model
  x_train ← RESHAPE x to column vector
  y_train ← RESHAPE y to column vector
  x_test ← RESHAPE x_test to column vector
  reg_model ← TRAIN LinearRegression model using (x_train, y_train)
  yHat_reg ← PREDICT y values using reg_model
  PLOT x_train vs. y_train (scatter) and x_test vs. yHat_reg (line)
  DISPLAY reg_model coefficients
  
```

```
// Step 5: Perform Statistical Analysis Using OLS
Regression
x1 ← ADD constant term to x
ols_model ← FIT OLS regression using (y, x1)
DISPLAY ols_model summary
END
```

The results indicated breakpoints at 150 meters for water bodies and 130 meters for dense vegetation. These breakpoints represent the saturation radii beyond which further increases in radius do not significantly enhance cooling effects, marking them as critical dimensions for optimizing the cooling performance of urban landscape features [26].

Table 2. Results from regression analysis

OLS Regression Results			
Dep. Variable:	Temperature	R-squared:	8.05
Model:	OLS	Adj. R-squared:	8.34
Method:	Least Squares	F-statistic:	2.96E+30
Date:	Sun, 14 Jul 2024	Prob (F-statistic):	0
Time:	13:20:18	Log-Likelihood:	3591.1
No. Observations:	114	AIC:	-7176
Df Residuals:	111	BIC:	-7168
Df Model:	2		

RESULTS AND DISCUSSIONS

Considering the individual water body, when we analyse the LST profile and create the cross-section along it, and the distance and change in temperature data is plotted on the graph (with temperature on the Y-axis and distance on the X-axis), we observe an S-curve pattern. The temperature profile follows an S-curve pattern. It begins at the center of the water body, where the temperature is lowest. As the distance from the center increases, the rate of temperature change decreases. Eventually, the temperature stabilizes and blends with the surrounding ambient temperature. This stabilization point defines the influence zone of the water body. Figure 11 displays the Land Surface Temperature (LST) distribution of Kankaria Lake, used as an example to demonstrate the cooling effect of water bodies.

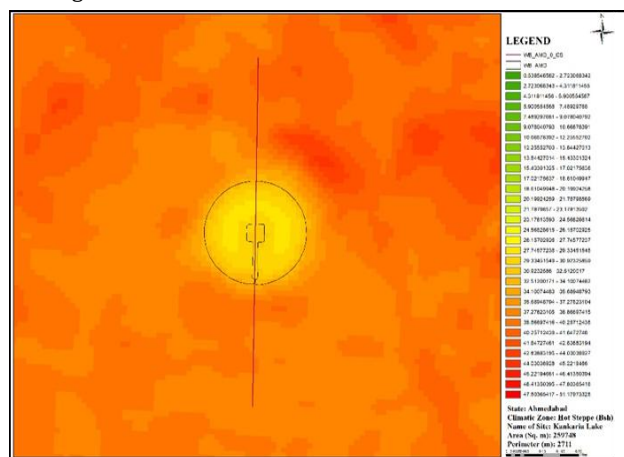


Figure 11. Radius against change in temp WB AMD

This graph shown in Figure 12 shows the temperature profile generated for a cross-section of Kankaria Lake, illustrating how temperature changes with distance from the water body.

Further in this study, 39 water bodies and 130 dense vegetation (DV) sites were analysed to determine the relationship between the radius of these landscape features and the change in temperature (ΔT) they induce in their surroundings. The analysis showed a direct relationship between the radius of a water body or green space and the change in surrounding temperature. However, this proportional relationship holds only up to a specific point. Beyond this threshold, further increases in size do not significantly impact temperature reduction. To understand this phenomenon, three cases were developed:

Case 1: Water Body with Radius R1 A water body with a radius R1 exhibits a change in temperature, denoted as $\Delta T1$, which is proportional to its size. In this initial case, the water body is relatively small, and its influence on the surrounding temperature is limited. The thermal influence is directly related to its radius, but it has not yet reached the threshold where the cooling effect stabilizes.

Case 2: Water Body with Radius R2 In the second case, a water body with a larger radius, R2, is analysed. The change in temperature here is $\Delta T2$. This scenario represents the ideal condition where the water body achieves its maximum cooling effect. The radius R2 is identified as the saturation radius (R_{sat}), where the thermal influence reaches its peak performance. Beyond this point, increasing the radius further does not significantly enhance the cooling effect, so $\Delta T2$ remains constant for any radius larger than R2.

Case 3: Water Body with Radius R3 For the third case, a water body with an even larger radius, R3, is considered. The corresponding change in temperature is $\Delta T3$. Despite the increase in size, the temperature change does not surpass $\Delta T2$, demonstrating that the cooling effect has stabilized. This reaffirms that R2 is indeed the saturation radius, and $\Delta T2$ represents the maximum potential cooling effect achievable by the water body. Figures 13-15 illustrate three conceptual cases used to explain the relationship between water body radius and temperature change, demonstrating how cooling effect varies with size.

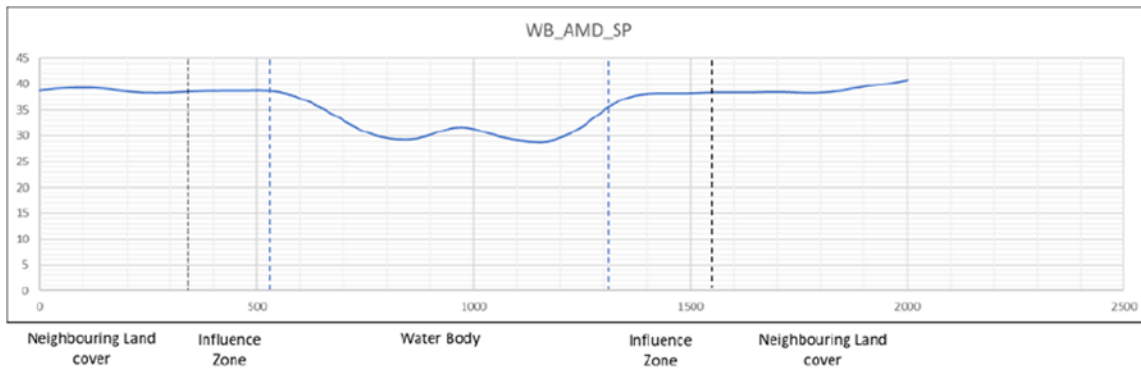


Figure 12. Stack profile generated for the shown C/S of Kankaria Lake

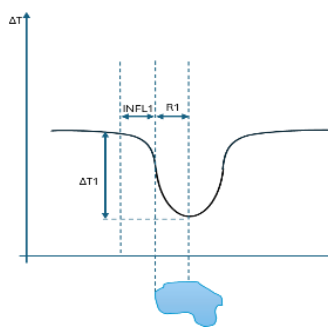


Figure 13. Case 1

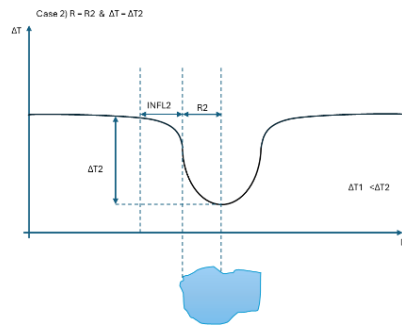


Figure 14. Case 2

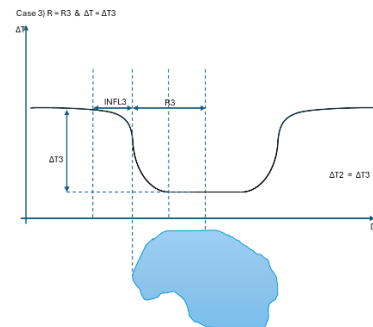


Figure 15. Case 3

Analysis and Implications

The relationships observed can be summarized as follows:

1. $R1 < R2 < R3$
2. $\Delta T1 < \Delta T2 = \Delta T3$

From these observations, it is concluded that the temperature change (ΔT) is directly proportional to the radius (R) of the water body, but only up to the saturation radius, $R2$. Beyond $R2$, the change in temperature remains constant, signifying the saturation point.

The saturation radius (R_{sat}) is the critical size beyond which the water body, dense vegetation attains its maximum performance in terms of thermal influence. This concept is crucial for urban microclimate studies, as it helps determine the optimal size of green or blue spaces for effective temperature regulation. Figure 16 combines the representations of the three conceptual cases, providing a comprehensive view of how cooling effect changes with increasing water body radius.

Hence the relationship for the analysis can be developed as follows,

$R \propto \Delta T$ but only up to $R2$ Because after $R2$ The ΔT becomes Constant

Therefore,

If $R1 < R_{sat}$, we use $R1$.

If $R3 > R_{sat}$, we use R_{sat} .

This graph shown in Figure 17 illustrates the relationship between water body radius and temperature change, highlighting the point at which the cooling effect reaches saturation.

This analysis concludes that for any climatic condition, the R_{sat} is the minimum or threshold dimension required to achieve the maximum possible performance in terms of cooling effect. The relationship for the analysis can be summarized as follows:

Saturation Point Determination

The analysis of the saturation point for water bodies and dense vegetation sites in Ahmedabad's climate was conducted using piecewise regression. Results show that breakpoint is near 150 meters for water bodies and 130 meters for dense vegetation. Additionally, ArcGIS was used to cross reference the saturation radii found to verify they are accurate.

R_{sat} of 150 meters is identified as a radius for water bodies. This is the critical threshold beyond which the radius increases by additional amount do not contribute much to the cooling effect but its extra amount. The piecewise regression analysis proved this breakpoint, as was a clear stabilization of the temperature change beyond this radius. This means that at 150 meters the potential for heating by water bodies has been reached and any additional cooling does not provide significant benefits.

Also, like saturated vegetation, the saturation radius is calculated to be 130 meters. This verifies that at radii beyond this value there is no additional effect for cooling off the temperature further, and increasing radii beyond this radius causes no further reduced temperature. The results regarding the piecewise regression showed that the cooling effect of dense vegetation sites stabilize at a distance of 130 meters, which is the optimal size of the construction under condition to ensure the maximum cooling benefit.

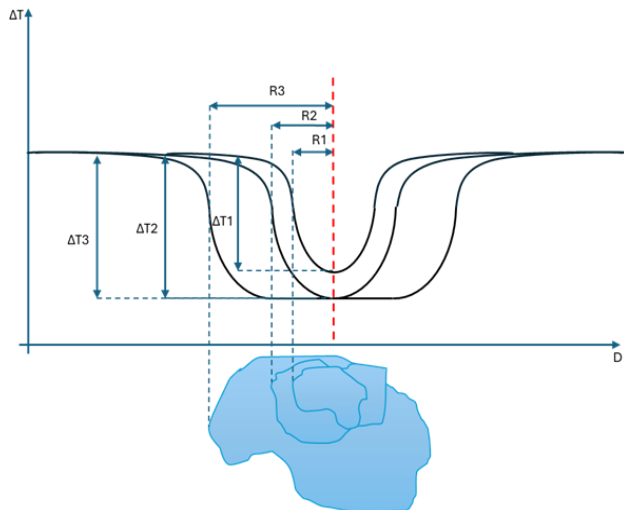


Figure 16. Combined representation of Case 1, 2 and 3

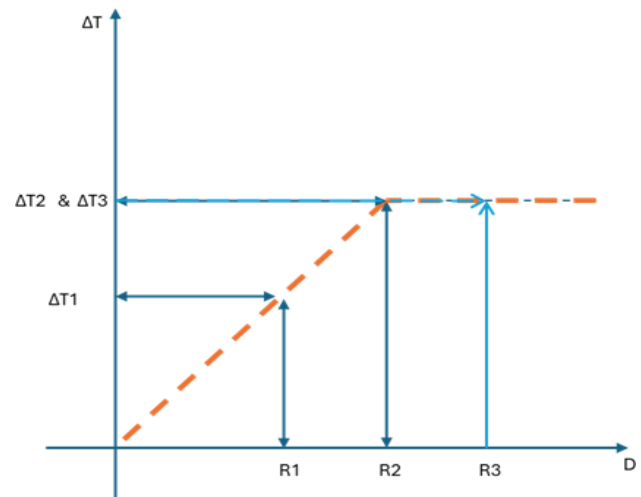


Figure 17. Radius against Change in Temperature Highlighting the relation between Radius and Change in Temperature of Water Body

Table 3. R_sat values for WB and DV AMD

City	Climatic Zone	Land use	T sat (°C)	ΔT_sat (°C)	R_sat (M)
Ahmedabad	Hot Steppe - Bsh	WB	29.65	8.785	150
		DV	35.52	2.916	130

This study yields valuable information regarding thermal regulation performance of landscape features in the urban environment. R_{sat} for water bodies in Ahmedabad for climate is a radius of 150m and for dense vegetation is a radius of 130m. The vignette is made relevant to urban planning because these saturation points are necessary to determine the optimum size of these features for max cool effect.

CONCLUSIONS

The findings in this study give important information concerning the thermal regulation performance of urban landscape features under hot steppe climatic conditions as observed in Ahmedabad. Water bodies and dense vegetation were found to have the Media (Max) (R_{sat}) – the Radius of Saturation at which the cooling effect is maximized. The R_{sat} was determined to be 150 meters for water bodies and 130 meters for dense vegetation. Results of these studies have important implications for urban planning and design under the hot climatic condition. As a result, city planners and designers can appropriately scale and localize the extent of water bodies and green spaces based on their cooling potential—i.e., the R_{sat}. This knowledge can help more effective strategy to mitigate urban heat island and improve thermal comfort in cities. Finally, the methodology used in this study that involves high resolution satellite image analysis, land surface temperature, and piecewise regression provides a strong approach for such studies in other urban areas. This could be extended to other climatic zones for future research, and examined how vegetation type, depth of the water body and surrounding urban fabric affects the cooling effect and R_{sat} values. Thus, this research advances understanding of more sustainability and climate resilient urban environments.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author and with permission from related parties.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest with any individual, institution, or organization in the preparation, evaluation, or publication of this study.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

There are no ethical issues with the publication of this manuscript.

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