The Cooling Effect of Canopy Cover and Surface Type: Measuring Urban Heat Island Mitigation in Nakhon Si Thammarat, Thailand

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Abstract

This pioneering study delves into the relationship between canopy cover, tree height, and surface temperatures in Nakhon Si Thammarat, Thailand. Our aim is to unravel how vegetation mitigates the effects of urban heat islands (UHI). Using densiometers for canopy cover measurement, clinometers and the Globe Protocol for tree height, and infrared thermometers for surface temperature data, we compared different land cover types (e.g., Dry Ground, Grass, Concrete, Metal Roof, Pond/Lake, Asphalt Road, Tall Shrubs, Trees) to assess their cooling potential. The results, which show that areas with higher canopy cover and taller trees exhibit significantly lower surface temperatures, underscore the pivotal role of green infrastructure in urban planning. This study provides actionable insights for reducing urban heat and improving environmental sustainability.

Keywords: Urban Heat Island, Canopy Cover, Tree Height, Surface Temperature, Green Infrastructure, Thailand, Densiometers

1. Introduction

1.1 Background

The urban heat island (UHI) effect, characterized by higher temperatures in urban areas than in rural surroundings, is a growing concern in rapidly urbanizing regions. Vegetation, particularly trees, is critical in mitigating UHI by providing shade, releasing moisture through transpiration, and reducing surface temperatures. This study focuses on measuring canopy cover, tree height, and surface temperatures of different land cover types in Nakhon Si Thammarat, Thailand, to evaluate the cooling effects of vegetation and inform urban planning strategies. Urban areas typically experience temperatures 2-4°C higher than surrounding rural regions, with some Asian cities recording differences up to 7°C during peak conditions [3]. This temperature disparity results from multiple factors, including:

- Reduced vegetation cover in urban areas [5]
- The replacement of natural surfaces with heat-absorbing materials [10]
- Anthropogenic heat emissions [14]
- Modified urban geometry affecting air circulation [15]

1.2 Research Context

Previous studies on UHI in Thailand have primarily focused on large metropolitan areas like Bangkok, leaving smaller cities and provinces, such as Nakhon Si Thammarat, relatively unexplored. Nakhon Si Thammarat, a rapidly urbanizing province in southern Thailand, offers a unique research context due to its tropical climate, coastal location, and diverse urban and rural landscapes. This study builds on earlier work by incorporating ground-based canopy cover measurements, tree height, and surface temperatures combined with the GLOBE Protocol for standardized data collection. By focusing on Nakhon Si Thammarat, this research contributes to a more comprehensive understanding of UHI patterns in diverse urban contexts across Thailand.

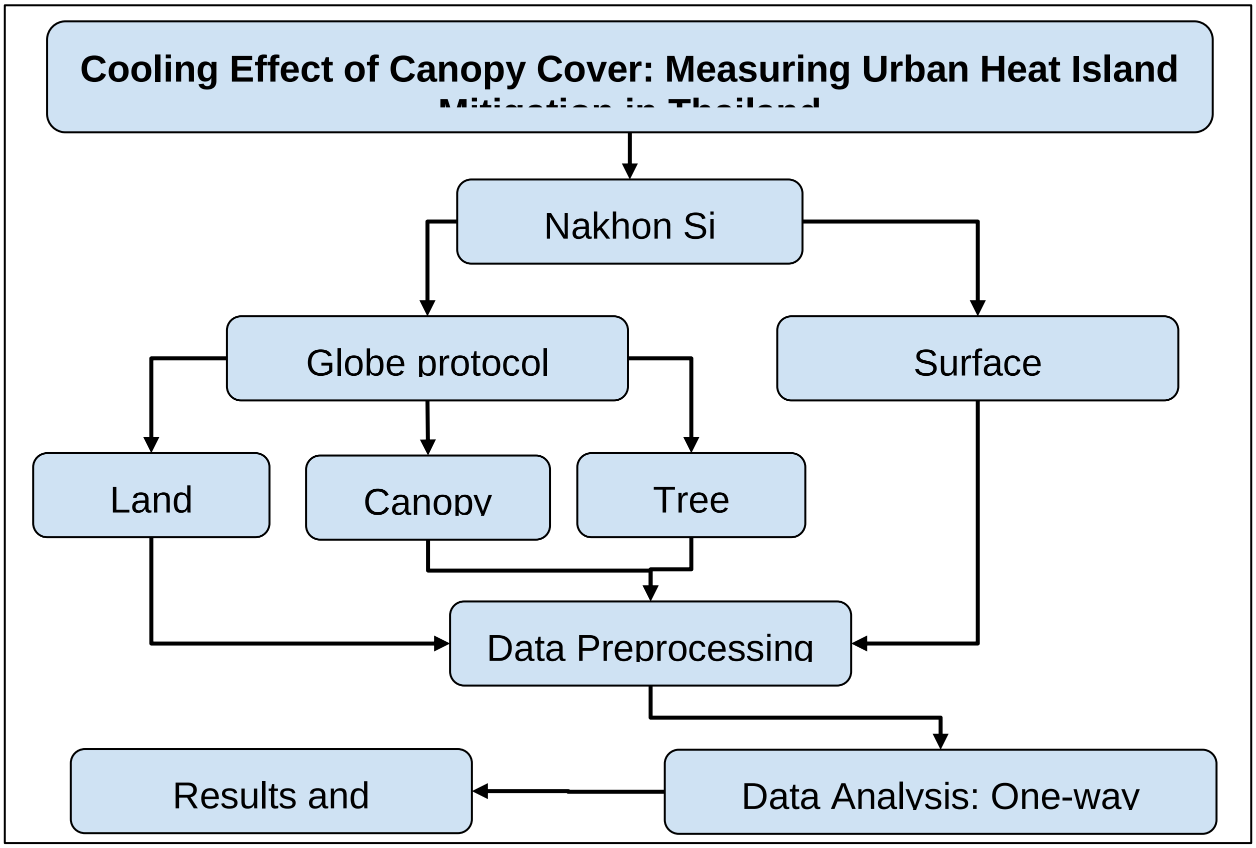


Figure 1: Experimental Design

1.3 Research Objectives

This study aims to:

- Quantify Canopy Cover and Tree Height: Use densitometers and clinometers to measure the percentage of canopy cover and the height of trees in different land cover types.
- Assess Surface Temperature Variations: Compare surface temperatures across various land cover types, including dry ground, grass, concrete, metal roofs, ponds/lakes, asphalt roads, tall shrubs, and trees.
- Evaluate Vegetation's Cooling Effects: Analyze the relationship between canopy cover, tree height, and surface temperatures to determine vegetation's cooling potential.
- Provide urban planning recommendations: The findings of this study can be used to develop actionable strategies for increasing green infrastructure and mitigating the effects of UHI in Nakhon Si Thammarat. These strategies could include increasing tree cover, creating green roofs, and

preserving water bodies, all of which have been shown to effectively reduce urban heat and improve environmental sustainability.

1.4 Significance

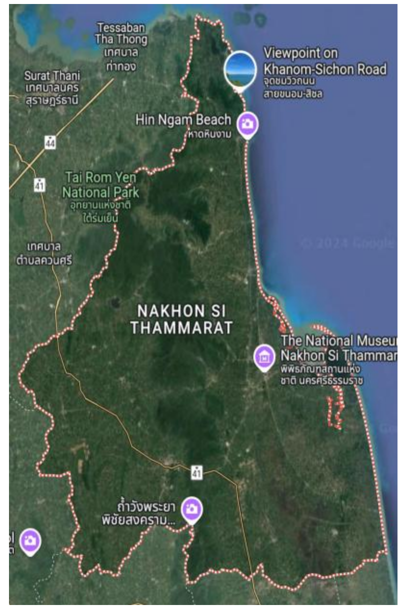
Understanding the relationship between vegetation and urban heat is crucial for several reasons. It not only provides evidence-based recommendations for incorporating green infrastructure into urban design but also holds the potential to significantly improve public health, environmental sustainability, and community awareness.

- Urban Planning and Development: This study provides evidence-based recommendations for incorporating green infrastructure into urban design, such as increasing tree cover, creating green roofs, and preserving water bodies.
- Public Health: By reducing urban heat, green spaces can lower the risk of heat-related illnesses, particularly for vulnerable populations like the elderly and outdoor workers.
- Environmental Sustainability: Vegetation helps mitigate climate change by sequestering carbon, improving air quality, and reducing energy consumption for cooling.
- Community Awareness: Engaging students and local communities in this research fosters awareness of the importance of green spaces and encourages collective action to combat urban heat.

2. Materials and Methods

2.1 Study Areas

This research was conducted in Nakhon Si Thammarat, Thailands:



Map acquired from Google Maps software application

Figure 2: Study location maps

2.2 Data Collection Methods

2.2.1 Ground-Based Measurements

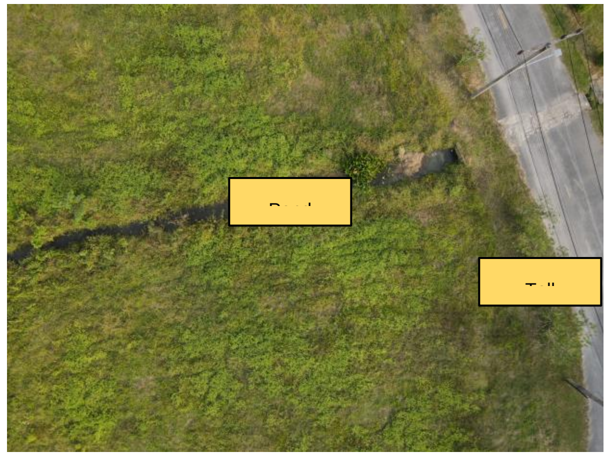
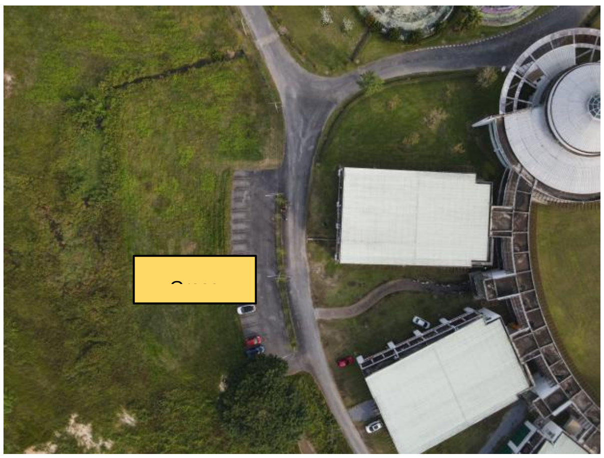
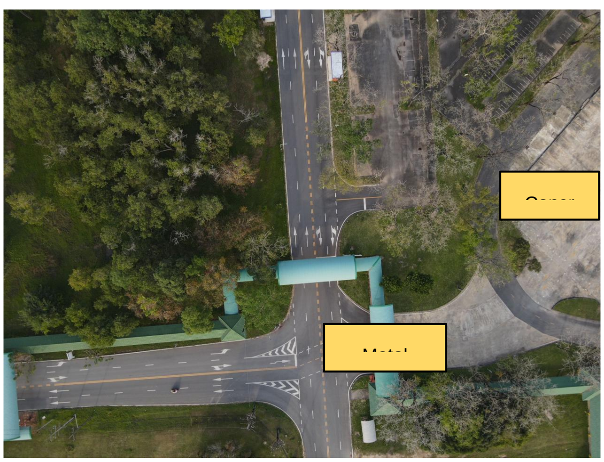
Temperature measurements were conducted using:

- Infrared thermometer gun (Model MESTEK IR03A, Range -50~400°C/600°C)
- GLOBE Protocol land cover, canopy cover, and Tree height observation tools
- Standard meteorological equipment for ambient conditions

2.2.2 Sampling Protocol:

- Ground shooting measurements taken at standardized heights (50 cm above ground)
- Three readings per point to ensure accuracy
- Data collected during both day (10:00-12:00) and night (18:00-20:00)

2.2.3. Surface types monitored:

	
	
	**Dry ground, Grass, Concrete, Metal roof, Pond/Lake, Asphalt road, Tall shrubs, Trees** Image acquired with drone.
Canopy Cover	

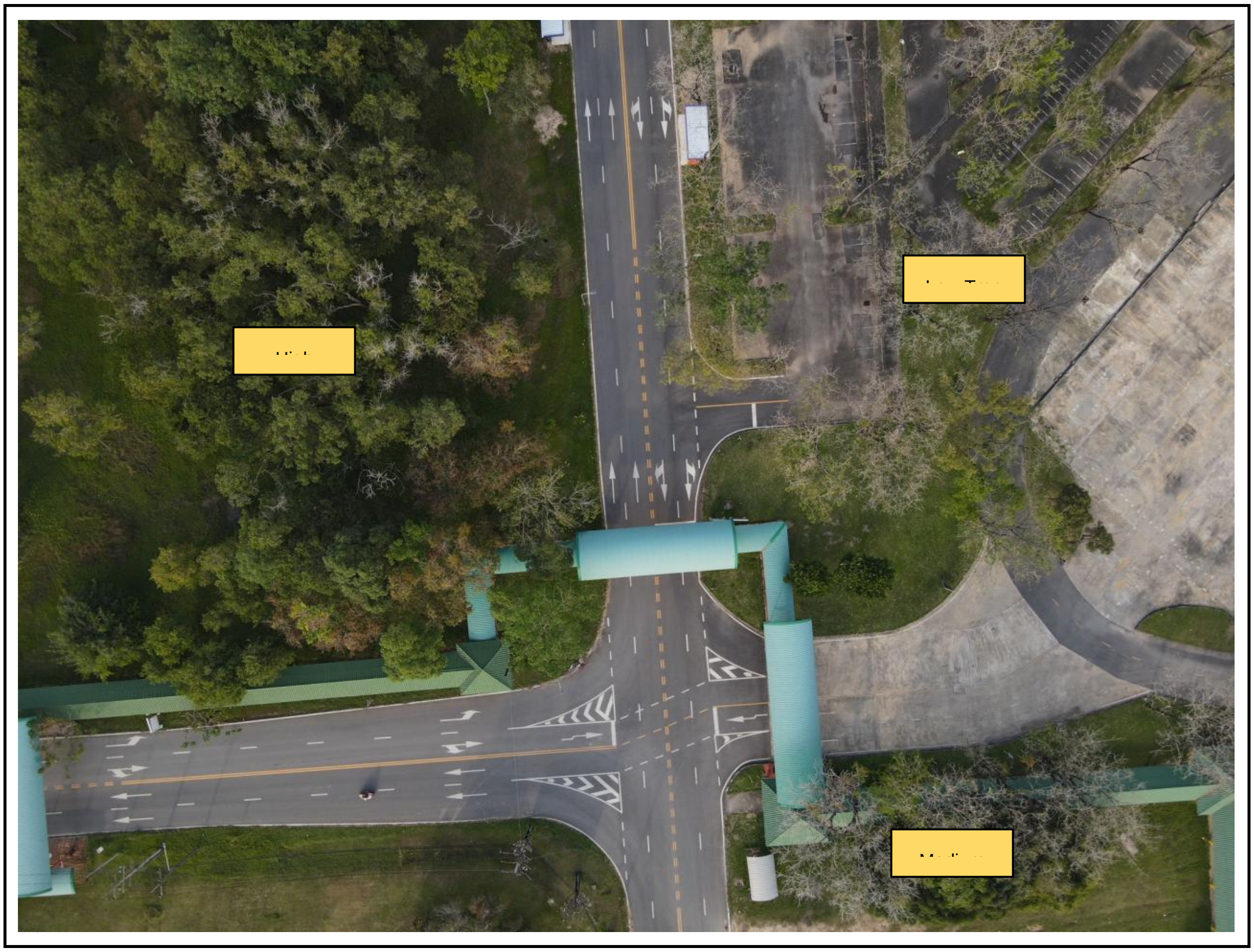


Figure 3: Ground shooting surfaces and Canopy Cover distribution

2.2.4 Canopy Cover Data

Canopy data collection:

- High-density tree vegetation.
- Moderate-density tree vegetation.
- Low-density tree vegetation.
- Tree height.
- Tree circumference

2.3 Data Analysis Methods

2.3.1 Statistical Analysis

The following analyses were performed:

- Descriptive statistics for each surface type for both day and night.
- Urban Heat Island Intensity Analysis

- One-way ANOVA to compare temperatures across surface types.
- Linear Regression for correlation analysis.
- Descriptive statistics.

2.4 Quality Control Measures

2.4.1 Instrument Calibration:

- Daily calibration of infrared thermometers
- Cross-validation with standard thermometers

2.4.2 Data Validation:

- Removal of outliers (>3 standard deviations)

2.4.5 Software and Tools

- Google Earth and Google Maps for spatial analysis and mapping
- Google Sheets with XLMiner for statistical analysis
- GLOBE Observer mobile application

3. Results

3.1 Surface Temperature Variations

3.1 Descriptive Surface Temperature Analysis

Table 2: Mean and Standard Deviation Day vs Nighttime Surface Temperatures (°C) by Surface Type

Surface Type	Day (deg C)	Afternoon (deg C)	Night (deg C)	Temperature Difference (deg C)
Dry Ground	28.35	42.51	29.83	17.4
Grass	29.79	39.18	23.26	8.6
Concrete	36.99	48.52	30.02	16.2
Metal Roof	41.60	48.64	21.32	19.0
Pond/Lake	14.13	23.73	26.98	1.7

Asphalt Road	38.75	49.07	32.39	4.0
Tall Shrubs	21.08	31.86	23.42	3.4
Trees	21.02	23.45	23.28	1.0

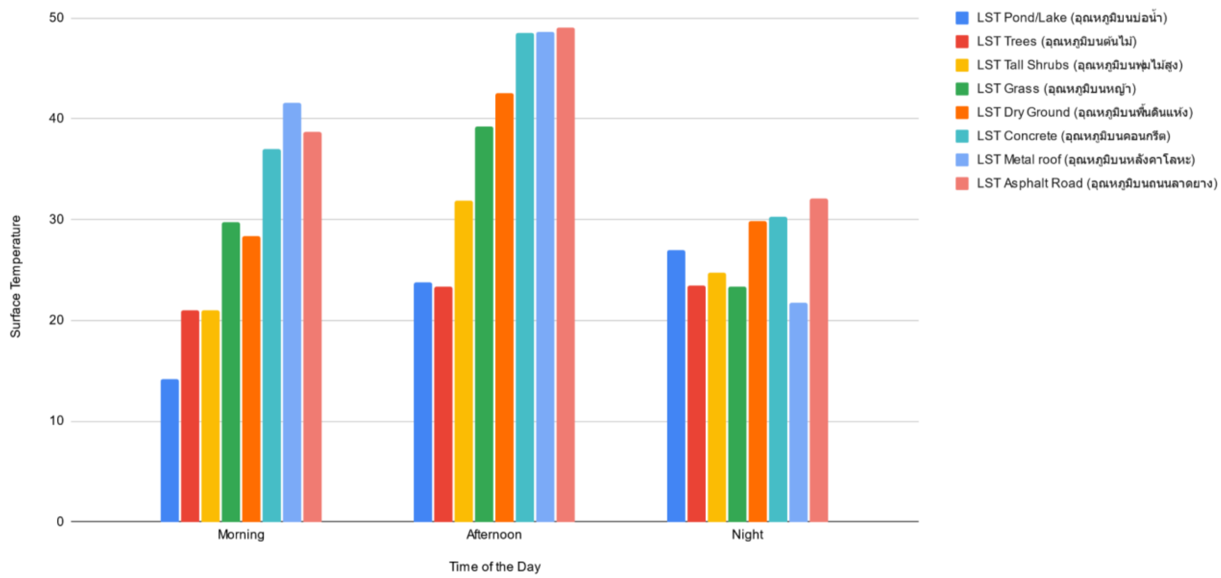


Figure 4: Bar chart comparing Morning vs Afternoon vs nighttime surface temperatures across different surface types

3.2 Statistical Analysis Results

Table 3: ANOVA Results for Surface Type Comparison by Morning

MORNING TIME						
Groups	*Count*	*Sum*	*Average*	*Variance*		
LST Dry Ground (อุณหภูมิบนพื้นดินแห้ง)	17	481.9	28.35	7.96		
LST Grass (อุณหภูมิบนหญ้า)	17	506.4	29.79	16.82		
LST Concrete (อุณหภูมิบนคอนกรีต)	17	628.9	36.99	24.90		
LST Metal roof (อุณหภูมิบนหลังคาโลหะ)	17	707.2	41.60	33.33		
LST Pond/Lake (อุณหภูมิบนบ่อน้ำ)	17	240.2	14.13	1.77		
LST Asphalt Road (อุณหภูมิบนถนนลาดยาง)	17	658.7	38.75	25.68		
LST Tall Shrubs (อุณหภูมิบนพุ่มไม้สูง)	17	358.4	21.08	7.76		
LST Trees (อุณหภูมิบนต้นไม้)	17	357.3	21.02	1.15		

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	11326.24	7	1618.03	108.44	0	2.08
Within Groups	1909.96	128	14.92			

Table 4: ANOVA Results for Surface Type Comparison by Afternoon

AFTERNOON TIME						
Groups	Count	Sum	Average (°C)	Variance		
LST Dry Ground (อุณหภูมิบนพื้นดินแห้ง)	17	722.7	42.51	6.23		
LST Grass (อุณหภูมิบนหญ้า)	17	666.2	39.19	8.44		
LST Concrete (อุณหภูมิบนคอนกรีต)	17	825	48.53	22.56		
LST Metal roof (อุณหภูมิบนหลังคาโลหะ)	17	827	48.65	22.05		
LST Pond/Lake (อุณหภูมิบนบ่อน้ำ)	17	403.5	23.74	2.06		
LST Asphalt Road (อุณหภูมิบนถนนลาดยาง)	17	834.2	49.07	21.51		
LST Tall Shrubs (อุณหภูมิบนพุ่มไม้สูง)	17	541.6	31.86	11.76		
LST Trees (อุณหภูมิบนต้นไม้)	17	397.3	23.37	11.95		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	13986.07	7.00	1998.01	149.99	0.00	2.08
Within Groups	1705.12	128.00	13.32			

Table 5: ANOVA Results for Surface Type Comparison by Night

NIGHTTIME						
Groups	Count	Sum	Average (°C)	Variance		
LST Dry Ground (อุณหภูมิบนพื้นดินแห้ง)	17	507.2	29.84	0.75		
LST Grass (อุณหภูมิบนหญ้า)	17	396.7	23.34	0.64		
LST Concrete (อุณหภูมิบนคอนกรีต)	17	515.3	30.31	55.32		
LST Metal roof (อุณหภูมิบนหลังคาโลหะ)	17	370.5	21.79	5.14		
LST Pond/Lake (อุณหภูมิบนบ่อน้ำ)	17	459.3	27.02	0.15		
LST Asphalt Road (อุณหภูมิบนถนนลาดยาง)	17	545.5	32.09	4.50		
LST Tall Shrubs (อุณหภูมิบนพุ่มไม้สูง)	17	419.7	24.69	17.40		
LST Trees (อุณหภูมิบนต้นไม้)	17	399.4	23.49	3.60		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1727.01	7.00	246.72	22.55	0.00	2.08

Within Groups	1400.25	128.00	10.94			

3.2 Overall Temperature Range:

The overall temperature range refers to the highest and lowest average temperatures recorded across all surface types and times of day. From the data:

- **Morning:** The highest average temperature is 41.60°C (LST Metal roof), and the lowest is 14.13°C (LST Pond/Lake). The range is 41.60 - 14.13 = 27.47°C.
- **Afternoon:** The highest average temperature is 49.07°C (LST Asphalt Road), and the lowest is 23.37°C (LST Trees). The range is 49.07 - 23.37 = 25.70°C.
- **Night:** The highest average temperature is 32.09°C (LST Asphalt Road), and the lowest is 21.79°C (LST Metal roof). The range is 32.09 - 21.79 = 10.30°C.

The overall temperature range across all times of day is 49.07°C (Afternoon, Asphalt Road) - 14.13°C (Morning, Pond/Lake) = 34.94°C.

3.3 Surface-by-Surface Comparison (Morning, Afternoon, and Night, °C):

This section analyzes and compares how different surfaces behave thermally across the day, highlighting trends and patterns:

1. **LST Dry Ground vs. LST Grass:**
   - **Dry Ground** is consistently warmer than **Grass** in the morning (28.35°C vs. 29.79°C) and afternoon (42.51°C vs. 39.19°C), but it cools slightly more at night (29.84°C vs. 23.34°C). This suggests that **Dry Ground** retains more heat during the day but loses it faster at night than **Grass**.
2. **LST Concrete vs. LST Asphalt Road**
   - Both surfaces are among the hottest, with **Asphalt Road** slightly warmer in the afternoon (49.07°C vs. 48.53°C). However, **Concrete** cools more at night (30.31°C vs. 32.09°C), indicating that **Asphalt Road** retains heat longer and contributes more to the UHI effect.
3. **LST Metal Roof:**
   - **Metal Roofs are the hottest surfaces** in the morning (41.60°C) and remain among the hottest in the afternoon (48.65°C). However, they cool dramatically at night (21.79°C), showing the most significant diurnal temperature swing. This makes them significantly contribute to the UHI effect during the day but less so at night.
4. **LST Pond/Lake vs. LST Trees:**

- **The pond/Lake** is the most astonishing surface in the morning (14.13°C) and remains relatively calm throughout the day (23.74°C in the afternoon). At night, it warms slightly (27.02°C), showing minimal variation. **Trees** also remain stable, with temperatures ranging from 21.02°C to 23.49°C. Both surfaces effectively mitigate heat, with the **Pond/Lake** slightly more incredible.

5. **LST Tall Shrubs:**
    - **Tall shrubs** exhibit moderate temperatures, staying cooler than artificial surfaces like **concrete** and **asphalt roads** but warmer than **trees, ponds/lakes**. This suggests they provide some heat mitigation but are less effective than fully vegetated or water-based surfaces.**3.5 UHI (Urban Heat Island) Implications:**

Key Insights:

1. **Largest Temperature Swings:**
    - LST Metal Roof and LST Asphalt Road show the most considerable diurnal temperature variations, with Metal Roof having the most dramatic swing (19.81°C). These surfaces absorb and release heat rapidly, exacerbating the UHI effect.
2. **Most Stable Surfaces:**
    - LST Pond/Lake and LST Trees are the most thermally stable, with minimal temperature fluctuations. These surfaces are critical for maintaining cooler microclimates in urban areas.
3. **UHI Implications:**
    - Artificial surfaces like LST Asphalt Road, LST Concrete, and LST Metal Roof significantly contribute to UHI by absorbing and retaining heat during the day. Their high temperatures and large swings highlight the need for urban planning strategies that incorporate more green spaces and water bodies to mitigate heat.
    - Natural surfaces like LST Trees, LST Grass, and LST Pond/Lake play a vital role in cooling urban environments, demonstrating the importance of preserving and integrating these elements into city landscapes.

3.6 Canopy cover vs surface temperature

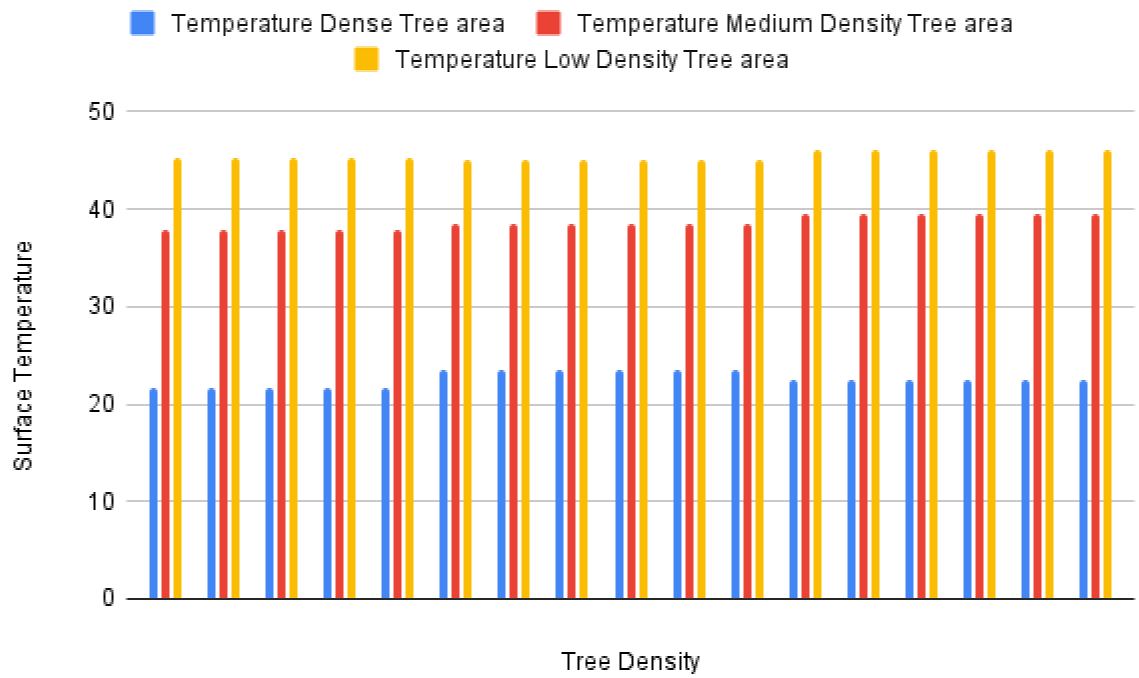


Figure 5: Canopy Cover temperature variation between dense, medium, and least dense tree areas.

3.4 Key Patterns and Analysis:

1. **Temperature Variations:**
   - Dense tree areas: 21.6–23.5°C (avg ≈ 22.5°C)
   - Medium density areas: 37.8–39.5°C (avg ≈ 38.6°C)
   - Low-density areas: 45.0–46.0°C (avg ≈ 45.4°C)
2. **Temperature Differential:**
   - Between dense and medium density: ~16°C
   - Between medium and low density: ~7°C
   - Total range (dense to low): ~23°C
3. **Tree Characteristics:**
   - Large trees: 27m height, 58cm diameter
   - Medium trees: 8m height, 48cm diameter
   - Smaller trees: 4.57m height, 34.5cm diameter

Key Insights:

1. **Cooling Effect Magnitude:**

- Dense tree areas show dramatic cooling effects (>20°C cooler than low-density areas)
- The most significant temperature drop occurs between low and medium-density areas.
- Even medium-density tree coverage provides substantial cooling compared to low-density areas.

2. **Density Thresholds:**
   - The 0.5-0.6 high-density threshold appears to be critical for maximum cooling benefits
   - Medium-density areas (0.4-0.6) still maintain significant cooling effects
   - Low-density areas (<0.2) show minimal cooling impact

4.0 Implications for Urban Planning

4.1 Surface Material Selection

Our findings suggest that urban planners should prioritize strategies that reduce heat absorption and enhance cooling. This includes minimizing the use of metal roofing materials [10], adopting green roof technologies, increasing the proportion of permeable surfaces, and incorporating water features into urban design[18].

4.1.1 Green Infrastructure and Canopy Cover

Given vegetation's significant cooling effect compared to hotter surfaces, implementing green infrastructure is crucial. This involves establishing urban forests and park networks, promoting green roofs and vertical gardens, implementing street tree programs, and protecting green corridors. Maintaining at least 50% high-density canopy tree coverage appears optimal for UHI mitigation; meanwhile, strategic placement of medium-density tree coverage and mixed-density approaches (0.5 high/0.5 medium) can provide significant cooling benefits.

4.2 Public Health and Environmental Implications

4.2.1 Heat-Related Health Risks

The observed temperature patterns raise concerns about potential health risks, particularly for vulnerable populations such as the elderly, outdoor workers, and children in schools with limited cooling.

4.2.2 Environmental Impact

The study highlights potential environmental consequences, including increased energy demand for cooling, altered local weather patterns, possible impacts on urban biodiversity, and implications for air quality.

4.3 Study Limitations

4.3.1 Methodological Constraints

The study's findings are subject to limitations related to the methodology, such as limited temporal coverage, fixed measurement times, accessibility constraints for ground-based measurements, and satellite data limitations such as cloud cover.

4.3.2 Geographic Scope

The focus on Nakhon Si Thammarat province may not fully represent the diverse urban contexts in Thailand. Further investigation is needed to assess coastal-inland variations and to increase the number of sampling points within the country.

4.4 Future Research Directions

4.4.1 Recommended Extensions

Future research should prioritize long-term monitoring programs, integration with air quality data, social vulnerability mapping, and climate change scenario modeling to advance understanding of urban heat islands and their impacts.

4.5.2 Methodological Improvements

Methodological advancements can enhance future research, including using higher-resolution satellite data, continuous monitoring stations, enhanced mobile sensing networks, and machine learning applications for prediction.

5.0 Conclusion

5.1 Summary of Findings

From the data, This study provides evidence of UHI effects in Nakhon Si Thammarat province, Thailand, demonstrating remarkable temperature variations between different surface types and varying densities of Canopy tree cover. The research highlights the critical role of surface materials and Canopy Cover in heat accumulation and dissipation.

5.2 Practical Applications

Our findings support the development of evidence-based urban planning strategies. These strategies include strategically placing green spaces, implementing guidelines for surface materials, promoting heat-resilient urban design, and developing public health protection measures.

5.3 Recommendations

Immediate Actions:

Immediate actions to address urban heat island effects include increasing urban vegetation coverage, implementing extraordinary roofing standards, protecting existing water bodies, and enhancing public awareness.

Long-term Strategies:

Long-term strategies require a more comprehensive approach, including the development of urban cooling plans, the revision of building codes and standards, the creation of climate-resilient urban designs, and the establishment of monitoring networks.

I would like to claim IVSS badges

1. **I have an impact**

The report clearly describes how a local issue led to the research question or connects local and global impacts. Students must clearly explain or demonstrate how the research has benefited their community by making recommendations or taking action based on the study's findings. This study, Mapping and Identifying Urban Heat Island Hotspots in Thailand: A Multi-Provincial Study Using Ground-Based and Satellite Measurements

2. **I am a STEM professional.**

The report clearly describes a collaboration with a STEM professional that improved the research methodology, contributed to greater rigor, and supported more sophisticated analysis and interpretation of the results. The data were used to analyze the results, and graphs were created to show relationships between the data.

3. **I am a data scientist.**

The report carefully examines the students' proprietary data and additional sources. Students will critically evaluate the limitations of these data, draw inferences about past, present, or future events, and use the data to answer questions or solve problems within the presented system. This may include gathering data from other academic institutions or using data from external databases. We developed a Cooling Effect of Canopy Cover and Surface Type: Measuring Urban Heat Island Mitigation in Nakhon Si Thammarat, Thailand.

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