



A COMPARATIVE STUDY OF GREEN SPACES AND THE URBAN HEAT ISLAND (UHI) EFFECT IN GEORGE TOWN, PENANG.

Cheah Wei Chee¹ & Mohd Ismail Isa²

*^{1,2} School of Housing, Building and Planning,
UNIVERSITI SAINS MALAYSIA*

Abstract

This study investigates the influence of green space on environmental quality and its role in mitigating the Urban Heat Island (UHI) effect, with a specific focus on George Town, Penang. By conducting a comparative analysis of two sites- Sia Boey Archaeological Park (Site A) and Little India (Site B)- within the urban setting, the research assesses variations in the Normalised Difference Vegetation Index (NDVI), land surface temperature (LST), and the Urban Thermal Field Variance Index (UTFVI) to evaluate their respective UHI impacts. Site A, characterised by integrated green areas, shows NDVI values ranging from 0 to 0.9, indicating dense, diverse vegetation. In contrast, Site B, which lacks substantial green space, exhibits a more limited NDVI range of 0 to 0.3. The LST analysis indicates that Site A experiences a broader temperature range (36°C to 51°C) than Site B (44°C to 50°C), suggesting that shaded regions within Site A mitigate surface temperatures. Although both sites exhibit similar UTFVI values (0- 0.02), the allocation of green spaces in Site A is associated with greater carbon sequestration and lower overall surface temperatures, emphasising the role of vegetation in reducing UHI intensity. These findings underscore the potential benefits of integrating green spaces within George Town's urban planning framework to substantially mitigate UHI effects, thereby advancing sustainable environmental management and enhancing urban climate resilience.

Keywords: Urban Heat Island (UHI), Urban Thermal Field Variance Index (UTFVI), Land Surface Temperature (LST), Normalised Difference Vegetation Index (NDVI)

² Corresponding author. Email: mohdismail.isa@usm.my

INTRODUCTION

This study aims to analyse and quantify the effectiveness of various green spaces in moderating urban temperatures and reducing UHI intensity in George Town. By mapping green coverage and correlating it with temperature data, researchers (Liu & Wang, 2023) seek to identify UHI hotspots and assess how green areas influence local climate conditions. This approach provides evidence-based insights for urban planning and policy decisions, emphasising the integration of green spaces as a core component of sustainable urban development. The study also highlights the broader socioeconomic benefits of green spaces, including enhanced quality of life, improved public health outcomes, and increased resilience to climate change. Future research should explore innovative green infrastructure solutions suited to George Town's urban context, utilising advanced remote sensing technologies to map green cover and temperature patterns accurately, and to evaluate long-term UHI mitigation strategies. By deepening our understanding of the relationship between green areas and urban heat dynamics, George Town can serve as a model for resilient, liveable cities that prioritise sustainability and community well-being amid ongoing urbanisation and climate change.

The comparative study of green areas and the UHI effect in George Town, Penang, addresses pressing issues related to urbanisation, climate change, and public health. Like many rapidly growing cities, George Town faces an intensifying UHI effect, in which urban areas are significantly warmer than their surrounding rural areas (Chan, 2014). The proliferation of heat-absorbing materials, such as concrete and asphalt, coupled with the reduction of green spaces, such as parks and urban forests, exacerbates this problem. Firstly, the UHI effect intensifies heat stress and public health risks, particularly for vulnerable populations such as the elderly, children, and outdoor workers (Braun et al., 2024). It also affects motivational and constraint factors that influence participation in outdoor recreation (Hasnizam et al., 2023). Prolonged exposure to elevated temperatures can lead to heat-related illnesses, reduced well-being, and diminished productivity. Secondly, the UHI effect places additional strain on urban infrastructure and increases cooling energy demand. Rising temperatures increase the use of air conditioning and refrigeration systems, leading to peak electricity demand that strains urban power grids. This situation elevates operational costs and contributes to higher greenhouse gas emissions, thereby aggravating climate change. These challenges in rapidly urbanising cities like George Town (Othman et al., 2021) underscore the importance of sustainable urban planning and resilient infrastructure investments.

Furthermore, the loss of green spaces accelerates environmental degradation and diminishes ecosystem resilience. As urban areas expand, natural landscapes such as forests and wetlands, which are crucial for biodiversity and

vital ecological services, are frequently cleared. Decreased vegetation cover hampers urban regions' capacity to mitigate air pollution, sequester carbon, and regulate local climates through evapotranspiration (Piracha & Chaudhary, 2022). Environmental harm from reduced greenery undermines biodiversity and diminishes the efficacy of green infrastructure in mitigating Urban Heat Island (UHI) effects and supporting climate change adaptation. Additionally, social and economic inequalities in access to green spaces and cooling resources (Sha & Cheng, 2024) exacerbate disparities in health outcomes and quality of life. Marginalised communities, often located in neighbourhoods with limited green spaces, bear a disproportionate share of the burden of heat-related risks and environmental hazards. This unequal distribution of amenities perpetuates social injustice and heightens vulnerability to climate change. The significance of this study resides in its potential to provide practical insights for urban planners and policymakers. The development of exemplary public spaces should involve the engagement of various stakeholders (Isa & Shan, 2024). As a UNESCO World Heritage site, George Town presents unique challenges in balancing heritage preservation with sustainable urban development. The findings from this research will assist planners in integrating green infrastructure into urban strategies while safeguarding the city's historical and cultural identity. Moreover, understanding the socio-economic benefits of green spaces, such as improved quality of life, enhanced public health, and reduced energy consumption, will establish a foundation for more resilient and sustainable urban development.

LITERATURE REVIEW

Assessing the variables of UHI phenomena

The UHI effect has become a focal point in urban climatology due to its profound impact on cities' sustainability, public health, and energy use. UHI (Figure 1) refers to the temperature disparity between urban and rural areas, primarily driven by human activities and by heat-absorbing materials such as concrete, asphalt, and dense buildings. These materials, with high thermal mass and low reflectivity (albedo), absorb and store heat during the day, gradually releasing it at night and resulting in elevated temperatures. Research on UHI has examined factors such as urban structure, land use, and vegetation distribution. Studies by Fadhil et al. (2012) have shown that urban geometry and surface materials significantly shape heat distribution across cities. Recent research has employed remote sensing and GIS to map temperature variations, highlighting the cooling effects of green spaces and water bodies. For example, Taylor et al. (2024) found that urban parks and tree-lined streets noticeably lower local temperatures through shading and evapotranspiration. Using NDVI in these studies has been essential for assessing vegetation cover and its relationship to surface temperatures.

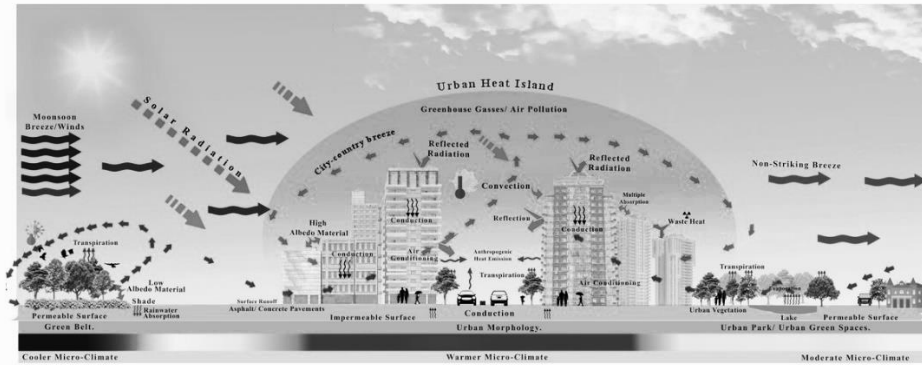


Figure 1: Conceptual framework for explaining the UHI phenomenon in city canyons.
Source: Siddique et al., 2020

Urban green spaces, including parks and street trees, are vital in mitigating the adverse effects of urbanisation, particularly the Urban Heat Island (UHI) effect. These areas provide cooling through shading, facilitate evapotranspiration, and reduce heat-absorbing surfaces, thereby effectively lowering urban temperatures (Raihan, 2024). Metrics such as NDVI indicate that regions with denser, healthier vegetation exhibit lower surface temperatures, underscoring the importance of dense green spaces (Rahaman et al., 2022). When strategically positioned, green spaces maximise cooling efficacy, diminish UHI intensity, reduce energy consumption, and enhance air quality. The effectiveness of green spaces depends on factors such as vegetation type, maintenance practices, and climate, with native species and broad-canopy trees providing optimal cooling benefits.

The Urban Thermal Field Variance Index (UTFVI) is a valuable metric in urban climatology that assesses the spatial variability of UHI by quantifying the variance in Land Surface Temperature (LST) across urban areas (Degerli & Cetin, 2023). The Urban Thermal Field Variance Index (UTFVI) is an extensively utilised indicator for evaluating ecological and environmental thermal conditions within urban environments. UTFVI measures thermal stress by comparing the land surface temperature (LST) at a specific location with the average LST of the designated study area. Elevated UTFVI values indicate greater thermal discomfort and a more pronounced Urban Heat Island (UHI) effect. In contrast, lower or negative values denote thermally comfortable conditions characterised by improved ecological quality. Accordingly, UTFVI is an effective tool for pinpointing urban thermal hotspots and assessing the environmental benefits of urban vegetation and green infrastructure. This index helps identify thermally intensive zones, providing insights into how urban features such as building density, vegetation, and surface materials influence UHI intensity. Research indicates that areas with high building density and limited

vegetation are associated with elevated UTFVI values, indicating more intense UHI effects, whereas regions with green spaces and water bodies tend to exhibit lower values due to their cooling effects (Jumari et al., 2023; Siddique et al., 2020). Despite its utility, the UTFVI is subject to seasonal and temporal variability, and ongoing research aims to refine the index and integrate it with other environmental metrics to provide a more comprehensive approach to UHI assessment.

Understanding the dynamics of Land Surface Temperature (LST) in George Town, Penang, is essential for evaluating the Urban Heat Island (UHI) effect and advancing urban climate resilience initiatives. Empirical research indicates that densely built urban regions with impervious surfaces, such as asphalt and concrete, tend to exhibit elevated LSTs due to their heat-retaining capacity. Conversely, green spaces help cool through shading and evapotranspiration, thereby reducing surface temperatures and enhancing thermal comfort (Cetin et al., 2024; Kandel et al., 2022; Mishra et al., 2019). The spatial variability of LST influences local microclimates, air quality, and public health outcomes. To measure LST, scholars employ satellite platforms equipped with thermal infrared sensors, such as Landsat, and analyse the data using Geographic Information Systems (GIS) software to generate temperature distribution maps, evaluate urban heat exposure, and validate results through ground truthing. This methodological approach supports the development of evidence-based strategies to mitigate LST, including augmenting green infrastructure and implementing sustainable land-use practices, thereby bolstering climate resilience in George Town and other urban areas.

Carbon sequestration is vital in George Town to mitigate the Urban Heat Island (UHI) effect and enhance climate resilience. The city actively captures atmospheric carbon dioxide through green spaces such as parks, urban forests, and gardens, thereby storing carbon in vegetation and soils and offsetting emissions from urban activities (Rahaman et al., 2022; Shadman et al., 2022; Taylor et al., 2024). These green areas also help lower surface temperatures through shading and evaporative cooling, particularly during heat waves, thereby mitigating UHI impacts. The calculation of carbon sequestration employs remote sensing techniques and field data to estimate carbon stocks in urban green spaces, supplemented by methodologies adapted from IPCC guidelines. These estimates are instrumental in informing sustainable urban planning, biodiversity conservation, and public health initiatives. In summary, research concerning environmental indicators such as UTFVI, NDVI, spatial distribution, and Land Surface Temperature (LST) has been conducted across various countries, including Turkey, China, Malaysia, Nigeria, Nepal, Indonesia, and the United States. Consistent findings highlight the significant influence of urban morphology, vegetation cover, and land use on local climate conditions and the

intensity of the urban heat island. NDVI, in particular, serves as a tool to quantify vegetation density and its cooling effects across different landscapes.

MATERIAL AND METHODS

The George Town, Penang, Sia Boey Archaeological Park, and Little India serve as valuable case study sites for examining the Urban Heat Island (UHI) effect within metropolitan environments abundant in cultural heritage. Both sites are located within the George Town UNESCO World Heritage Site and exhibit unique architectural and spatial characteristics that influence local microclimates, making them pertinent to UHI research. Sia Boey Archaeological Park (see Figure 2), a green space surrounded by historic structures and dense urban development, offers an opportunity to analyse how vegetated areas in a heritage context can mitigate UHI effects. Its design, which integrates open spaces and greenery amid preserved colonial buildings, contrasts with the surrounding urban environment, which is composed of heat-retentive surfaces such as concrete and asphalt. Conversely, Little India (see Figure 3), characterised by a compact layout, narrow streets, and historic shophouses, offers a contrasting environment for UHI studies. The densely built environment, combined with the extensive utilisation of heat-absorbing materials, creates conditions conducive to heat retention and limited air circulation. Analysing UHI patterns in Little India can provide insights into how densely developed heritage zones with limited vegetation respond to increasing urban temperatures.

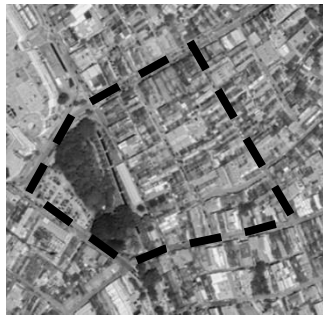


Figure 2: Study Site A.

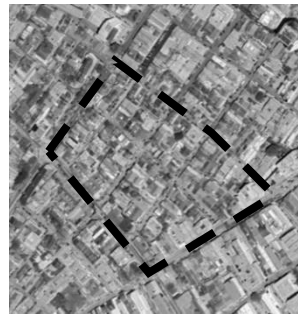


Figure 3: Study Site B.

An advanced Geographic Information System (GIS) based analysis is employed to effectively examine the Urban Heat Island (UHI) effect in George Town, Penang, utilising key environmental variables extracted from Landsat 8 satellite data via Google Earth Engine (GEE). The study incorporates explicitly the Normalised Difference Vegetation Index (NDVI), Land Surface Temperature (LST), and Universal Thermal Climate Index (UTFVI), each serving a distinct function in understanding urban heat dynamics. Each dataset is processed in

GEE, with NDVI calculated from Landsat 8's red and near-infrared bands, and LST derived from the thermal infrared band. UTFVI values are computed by correlating LST and NDVI data to map variability in the thermal field.

These datasets are exported as GeoTIFF files for high-resolution spatial analysis in ArcMap. The layers are overlaid and reprojected to align with George Town's coordinate system, ensuring spatial accuracy and precise visualization. The Raster Interpolation Analysis tool generates continuous surface maps from point data, interpolating across gaps for comprehensive spatial insights. This tool estimates values at unsampled locations from known data points, enabling the visualisation of gradients and spatial patterns, which is particularly advantageous when working with environmental datasets such as NDVI, LST, and UTFVI. During raster interpolation for the UHI study in George Town, Penang, the tool uses temperature data points to generate a smooth temperature surface across the city. Data points with known LST are interpolated to estimate LST values at intermediate locations. The resulting output is a continuous raster surface map that highlights temperature variations across the study area, facilitating high-precision identification of UHI intensity and hotspots.

Interpolation creates a surface map of Land Surface Temperature (LST) that can be layered with datasets like NDVI and UTFVI. This helps analysts study relationships between vegetation, urban growth, and temperature, offering key insights for urban planning to reduce Urban Heat Island (UHI) effects. The tool highlights spatial patterns visually and quantitatively, guiding urban cooling and greening policies to promote resilient development. In 2014, the land surface temperature at Site A (Figure 4) ranged from 45°C to 51°C, with an average temperature higher than that recorded in 2024. This rise is ascribed to the completion of the Sia Boey Archaeological Park in 2019, which has demonstrated the efficacy of green spaces in alleviating urban heat island (UHI) effects. Conversely, the 2014 findings for Site B (Figure 5) show slight differences due to the absence of designated green areas. Moreover, this is corroborated by a comparison of NDVI values. The NDVI values for Site A (Figure 6) in 2014 were markedly lower than those in 2024, whereas the NDVI values for Site B (Figure 7) remained unchanged over the ten years.

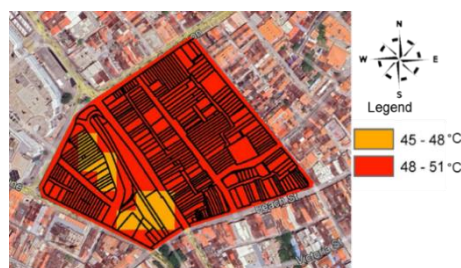


Figure 4: LST of Site A in 2014.



Figure 5: LST of Site B in 2014.

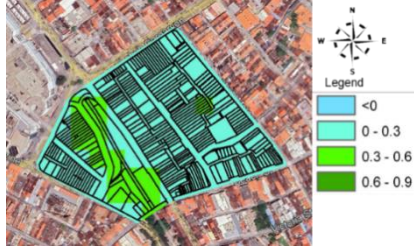


Figure 6: NDVI of Site A in 2014.

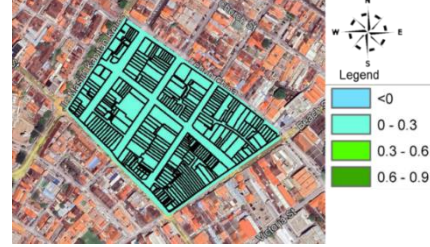


Figure 7: NDVI of Site B in 2014.

Landsat 8 Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS) imagery was obtained through Google Earth Engine (GEE) to evaluate temporal changes in vegetation cover and land surface temperature. Two cloud-free scenes representing conditions before and after the development of Sia Boey Archaeological Park were selected. The Landsat imagery has a spatial resolution of 30 m for multispectral bands and 100 m for thermal bands, with the thermal bands resampled to 30 m.

The selected images were acquired with cloud cover below 10% to minimise atmospheric interference. Standard preprocessing procedures, including radiometric calibration, atmospheric correction, and cloud masking, were performed in GEE prior to further analysis.

The Normalised Difference Vegetation Index (NDVI) was calculated using Equation (1):

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

Where NIR represents Landsat Band 5 and Red represents Landsat Band 4.

Land Surface Temperature (LST) was derived from Landsat 8 thermal Band 10 using a multi-step procedure involving conversion of Digital Number (DN) values to spectral radiance, calculation of brightness temperature, emissivity correction, and final temperature conversion. Surface emissivity (ϵ) was estimated using the NDVI Threshold Method based on the proportion of vegetation cover.

The Urban Thermal Field Variance Index (UTFVI) was subsequently computed using:

$$UTFVI = \frac{LST - LST_{mean}}{LST_{mean}}$$

Where LST denotes the land surface temperature of each pixel, and LSTmean represents the average temperature of the study area. The resulting UTFVI values were classified into six environmental quality classes ranging from “Excellent” to “Worst” ecological conditions.

RESULTS AND DISCUSSION

At Site A (refer to Figure 8), the dominant land use is commercial, occupying 9.55 acres, constituting 61% of the total 15.54-acre area. Green spaces are the subsequent most prevalent land use, covering 2.34 acres (15%), followed by development land at 2.25 acres (14%), facilities spanning 1.01 acres (6%), with smaller allocations for parking (0.08 acres, 1%), water bodies (0.25 acres, 2%), and a minimal mixed-use area at 0.06 acres. Conversely, Site B (refer to Figure 9) primarily consists of commercial land use, with 9.63 acres (96%) allocated to this purpose and facilities covering only 0.42 acres (4%) of the 10.15-acre site.



Figure 8: Land Use Activities of Site A in 2019.

Source: Majlis Bandaraya Pulau Pinang, 2019



Figure 9: Land Use Activities of Site B in 2019.

Source: Majlis Bandaraya Pulau Pinang, 2019

The analysis of NDVI values reveals notable disparities among sites, indicating differences in vegetation cover. Site A (see Figure 10) exhibits a broad NDVI range from 0 to 0.9, with higher values in green spaces, indicative of vigorous vegetation, and lower values in commercial zones, suggesting sparse or absent vegetation. In contrast, Site B (see Figure 11) displays a consistently narrow NDVI range of 0 to 0.3, reflecting a deficiency of green spaces and an area predominantly characterised by impervious surfaces underpinned by commercial land use.



Figure 10: NDVI of Site A in 2014.



Figure 11: NDVI of Site B in 2024.

The analysis of Land Surface Temperature (LST) further delineates the distinctions between the two sites. The LST at Site A (see Figure 12) exhibits considerable fluctuations, ranging from 36°C to 51°C, reflecting a mixture of shaded and sun-exposed surfaces, potentially moderated by green spaces that aid in heat management. In contrast, Site B (see Figure 13) exhibits a narrower LST range of 44°C to 50°C, indicating more uniform and possibly elevated surface temperatures, likely due to the presence of a commercial hardscape landscape with minimal vegetation. The Urban Thermal Field Variance Index (UTFVI) analysis highlights significant differences in environmental thermal quality between these two locations. Although both sites show UTFVI values spanning from 0 to above 0.02, their spatial distributions vary considerably. Site A features larger areas within advantageous UTFVI categories, especially in regions proximate to vegetation, open spaces, and water features. These zones suggest reduced thermal stress and enhanced ecological conditions.

In contrast, Site B exhibits a markedly higher proportion of pixels classified in the “Poor”, “Bad”, and “Worst” environmental quality categories, indicating increased thermal discomfort and intensified Urban Heat Island (UHI) effects. The predominance of impervious surfaces, densely constructed buildings, limited sky-view factors, and scarce vegetation contribute to the sustained elevation of thermal conditions across the site. The findings underscore that the mere presence of green space is inadequate; rather, its spatial configuration, connectivity, canopy density, and integration with surrounding urban land uses are equally critical. Moreover, the results demonstrate that even relatively small urban green spaces can provide measurable cooling benefits when strategically situated within densely developed heritage districts. Site A (Figure 14) is likely situated within more favourable categories due to its green spaces, which mitigate heat and result in lower Urban Tree Vegetation Index (UTFVI) values. Conversely, Site B (Figure 15), characterised predominantly by commercial land use, is likely to fall within lower UTFVI categories.



Figure 1: LST of Site A in 2024.



Figure 2: LST of Site B in 2024.



Figure 14: UTFVI of Site A.



Figure 15: UTFVI of Site B.

Validation using ground-based measurements (Figures 16 and 17) supports the findings, demonstrating a strong correlation between remote-sensing data and actual surface conditions. To verify the accuracy of remotely sensed LST values, we conducted field measurements at representative locations within both study sites during daytime observations. Surface temperatures were recorded using a handheld infrared thermometer at selected points representing vegetated surfaces, paved areas, building surfaces, and open spaces. The geographic coordinates of each measurement point were recorded using a GPS-enabled mobile device. The field observations were subsequently compared with corresponding Landsat-derived LST values. The comparison revealed a strong consistency between satellite-derived temperatures and observed field conditions, confirming the reliability of the remote sensing approach for evaluating thermal variations in George Town. Although slight deviations were observed due to differences in measurement scale and acquisition timing, the overall temperature distribution patterns were highly comparable.

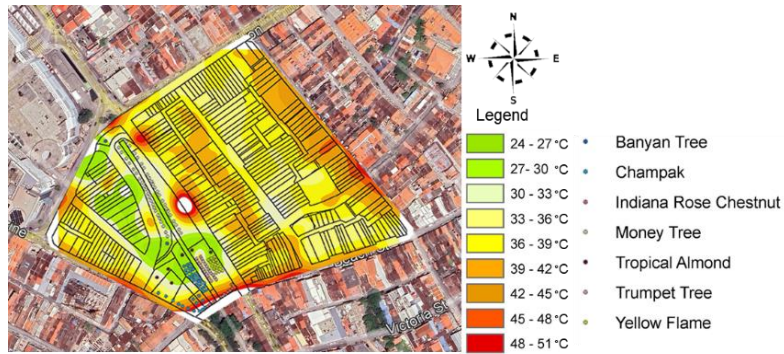


Figure 16: Surface Temperature in Site A captured by on-ground survey.

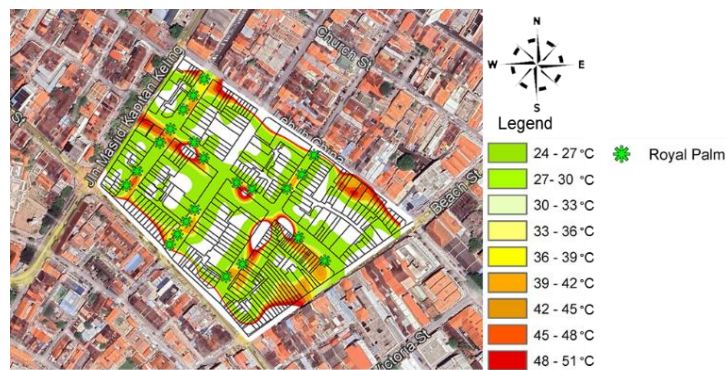


Figure 17: Surface Temperature in Site B captured by on-ground survey.

Table 1: Summary of the findings.

No.	Variable	Findings	
		Site A	Site B
1.	NDVI	Varies from 0 to 0.9	Varies from 0 to 0.3
2.	LST	Varies from 36°C to 51°C	Varies from 44°C to 50°C
3.	UTFVI	Varies from 0 to 0.02	Varies from 0 to 0.02
4.	Spatial Distribution	The green area is allocated	No green area

Source: Authors, 2024

This validation process ensures reliability by confirming that remote sensing accurately captures on-the-ground variations in vegetation cover, surface temperature, and urban thermal stress, emphasising the impact of land-use composition on environmental quality across these sites. Table 1 summarises the findings and data interpretation. The results from land-use, NDVI, LST, and

UTFVI analyses directly support key development strategies, environmental policies, and climate-responsive design principles. Site A, with a balanced mix of commercial zones, green spaces, and supporting facilities, aligns with planning standards that promote diverse land use, sufficient open spaces, and the integration of green infrastructure. Conversely, Site B's predominantly commercial character and scarce vegetation conflict with sustainable development policies that advocate urban greenery, heat mitigation, and public amenities. NDVI results show healthier vegetation at Site A, supporting green infrastructure and low-carbon city goals, while Site B's low vegetation indicates non-compliance with urban greening standards. LST patterns reveal cooling effects from greenery at Site A, in line with climate-responsive urban design, whereas higher temperatures at Site B highlight the impact of excessive hard surfaces. UTFVI analysis further confirms these differences, with Site A closer to favourable environmental quality categories and Site B showing signs of thermal stress, highlighting the importance of adhering to planning and environmental guidelines. Overall, these findings illustrate how land-use composition significantly affects environmental quality, aligning with the goals and requirements of contemporary urban planning.

Study Limitations

Although the comparative analysis offers valuable insights into the influence of green spaces on urban thermal conditions, the study is restricted by its focus on only two sites within George Town. Sia Boey Archaeological Park and Little India exemplify contrasting urban environments; however, they may not fully encompass the diversity of land-use types and urban morphological characteristics present throughout the city. Accordingly, the findings should be regarded as case-specific rather than universally representative of George Town. Future research should incorporate a greater number of sites, including residential neighbourhoods, waterfront areas, industrial districts, and mixed-use zones, to enhance the generalizability of results and facilitate a more comprehensive understanding of UHI dynamics.

Planning and Design Implications

The findings are of considerable significance for climate-responsive urban planning in George Town and other cities characterised by high-density heritage precincts. Primarily, the development of additional pocket parks in underutilised urban areas can increase vegetation cover and establish localised cooling islands in densely built-up zones such as Little India. Small-scale green spaces, tactically positioned throughout the urban landscape, often achieve greater efficacy in enhancing pedestrian thermal comfort than a single large park at a distance. Furthermore, the implementation of a comprehensive street tree planting

programme along principal pedestrian thoroughfares and commercial streets is recommended. Indigenous and broad-canopy tree species can provide shade, diminish pavement temperatures, enhance walkability, and promote urban biodiversity.

Thirdly, local authorities should promote the utilisation of cool materials, including high-albedo pavements, reflective roofing materials, and permeable surfaces. These measures can substantially diminish heat absorption and decrease surface temperatures in densely urbanised areas. Fourthly, the development of shaded pedestrian corridors should be prioritised, especially within heritage tourism zones. Continuous shade provision through tree canopies, covered walkways, and arcades can markedly enhance outdoor thermal comfort, minimise heat exposure, and foster active mobility. Lastly, urban planners should establish a network of interconnected green corridors linking major parks, riverfronts, open spaces, and heritage districts. Green corridors facilitate airflow, improve ecological connectivity, aid urban cooling, and bolster climate resilience at the metropolitan level. Such measures are particularly pertinent for George Town, where balancing heritage preservation with climate adaptation has become an increasingly significant planning challenge.

CONCLUSION

This study investigates the Urban Heat Island (UHI) phenomenon in George Town, Penang, with particular focus on the influence of green spaces on UHI intensity and spatial distribution within two primary areas: Sia Boey Archaeological Park (Site A) and Little India (Site B). Employing advanced remote sensing techniques and high-resolution spatial data, the research's initial objective is to map and analyse the distribution of green areas, thereby revealing notable disparities in vegetation cover between the two sites. Site A, characterised by extensive green spaces, exhibits a broad range of NDVI values (0-0.9), indicative of diverse and vigorous vegetation. Conversely, Site B's NDVI values are confined to a narrow range of 0-0.3, indicating sparse vegetation and limited green infrastructure. These distinctions highlight the critical importance of urban planning that prioritises the allocation of green space, as areas with denser vegetation directly contribute to cooling effects and mitigate the adverse consequences of urbanisation.

LST analyses further emphasise the cooling benefits of greenery, with Site A exhibiting greater LST variation (36°C to 51°C) than Site B (44°C to 50 °C). This wider range indicates that Site A's vegetation and shaded areas help to regulate surface temperatures, fostering a more favourable microclimate. Using UTFVI, the study classifies environmental conditions and corroborates remote sensing data with on-the-ground measurements. Site A's UTFVI values indicate a healthier environment, attributable to higher vegetation density and strategically

placed green spaces, which directly enhance carbon sequestration and provide essential thermal regulation. Combining remote sensing, ground truthing, and ArcGIS spatial analysis ensures data precision and deepens understanding of UHI patterns across George Town's diverse urban landscape.

In conclusion, the study, utilising spatial analysis and visualisations in ArcGIS, demonstrates that green spaces are instrumental in alleviating Urban Heat Island (UHI) effects. Site A exemplifies effective urban planning. The findings indicate that areas with allocated green spaces exhibit lower land-surface temperatures, reduced UHI intensity, and higher carbon sequestration rates, suggesting that expanding urban greenery could substantially improve George Town's sustainability. For policymakers and urban planners, this evidence-based analysis underscores the importance of incorporating additional green infrastructure in densely developed areas such as Little India. The comprehensive methodology employed in this study provides a strategic framework for addressing the UHI challenge, integrating academic insights with practical recommendations to augment the livability and environmental resilience of George Town through targeted urban greening initiatives.

ACKNOWLEDGEMENTS

The authors thank Universiti Sains Malaysia, under Project Code R502-KR-GOT001-0000000152-K134, and the School of Housing, Building and Planning, Universiti Sains Malaysia, for their financial support for this research.

REFERENCES

- Braun, P., Lookingbill, T., Zizzamia, B., Hoffman, J., Rosner, J., & Banta, D. (2024). A Heat Emergency: Urban Heat Exposure and Access to Refuge in Richmond, VA. *GeoHealth*, 8(6). <https://doi.org/10.1029/2023GH000985>
- Cetin, M., Ozenen Kavlak, M., Senyel Kurkcuoglu, M. A., Bilge Ozturk, G., Cabuk, S. N., & Cabuk, A. (2024). Determination of land surface temperature and urban heat island effects with remote sensing capabilities: the case of Kayseri, Türkiye. *Natural Hazards*, 120(6), 5509–5536. <https://doi.org/10.1007/s11069-024-06431-5>
- Chan, N. W. (2014). Urbanisation and the Generation of Urban Heat Islands in Selected Malaysian Cities. <https://www.researchgate.net/publication/282664448>
- Degerli, B. C., & Cetin, M. (2023). Evaluation of the effect of the UTFVI index on climate change in terms of urbanisation. *Environmental Science and Pollution Research*, 30(30), 75273–75280. <https://doi.org/10.1007/s11356-023-27613-x>
- Eboy, O. V., & Kemarau, R. A. (2023). Analysis of Extreme Heat Land Surface Temperature at a Tropical City (1988-2022): A Study on the Variability of Hot Spot during El Niño Southern Oscillation (ENSO). *Science and Technology Indonesia*, 8(3), 388–396. <https://doi.org/10.26554/sti.2023.8.3.388-396>
- Fadhil, M., Din, M., Dzinun, H., Mohanadoss, P., Ponraj, M., Chelliapan, S., Noor, Z. Z., Remaz, D., & Iwao, K. (2012). Investigation of thermal effect on exterior wall

- surface of building material at urban city area. *International Journal of Energy and Environment*.
- González, O., Nájera González, A., Marcelleño Flores, S. M. L., & Flores Vélchez, F. (2024). Influence of ENSO and the urban heat island on climate variation in a growing city of the western Mexico. *One Ecosystem*, 9. <https://doi.org/10.3897/oneeco.9.e125302>
- Hasnizam Ab Dulhamid, Mohd Ismail Isa, Badaruddin Mohamed, Muhammad Ferdhaus Sazali, & Nurbaidura Salim. (2023). An Examination of Outdoor Recreation Participation Constraints Among Rural and Urban Communities. *Journal of the Malaysian Institute of Planners*, 21(4), 510–524. <https://doi.org/10.21837/pm.v21i28.1349>
- Hu, Y., Tan, J., Grimmond, S., Ao, X., Yan, Y., & Liu, D. (2022). Observed and Modelled Urban Heat Island and Sea-Breeze Circulation Interactions: A Shanghai Case Study. *Journal of Applied Meteorology and Climatology*, 61(3), 239–259. <https://doi.org/10.1175/JAMC-D-20-0246.1>
- Isa, M. I., & Shan, A. Q. (2024). The Value of Arts and Culture: A Case Study on Creative Placemaking in Hin Bus Depot, Penang, Malaysia. *Planning Malaysia*, 22(34). <https://doi.org/10.21837/pm.v22i34.1643>
- Jumari, N. A. S., Ahmed, A. N., Huang, Y. F., Ng, J. L., Koo, C. H., Chong, K. L., Sherif, M., & Elshafie, A. (2023). Analysis of urban heat islands with landsat satellite images and GIS in Kuala Lumpur Metropolitan City. *Heliyon*, 9(8). <https://doi.org/10.1016/j.heliyon.2023.e18424>
- Kemarau, R., & Eboy, O. V. (2021). The influence of El Niño Southern Oscillation on urban heat island formation at a tropical city: Case of Kuching City, Sarawak. *Malaysian Journal of Society and Space*, 17(4). <https://doi.org/10.17576/geo-2021-1704-20>
- Kemarau, S., Gyawali, B., Sandifer, J., Shrestha, S., & Upadhaya, S. (2022). Assessment of Urban Heat Islands (UHIs) Using Satellite-Derived Normalised Difference Vegetation Index (NDVI), and Land Surface Temperature (LST) in Three Metropolitan Cities of Nepal. *Banko Janakari*, 32(2), 37–51. <https://doi.org/10.3126/banko.v32i2.50895>
- Liu, Y., & Wang, Z. (2023). Research Progress and Hotspot Analysis of Urban Heat Island Effects Based on Cite Space Analysis. *Land*, 12(6). <https://doi.org/10.3390/land12061154>
- Luo, F., Yang, Y., Zong, L., & Bi, X. (2023). The interactions between urban heat island and heat waves amplify urban warming in Guangzhou, China: Roles of urban ventilation and local climate zones. *Frontiers in Environmental Science*, 11. <https://doi.org/10.3389/fenvs.2023.1084473>
- Mishra, B., Sandifer, J., & Gyawali, B. R. (2019). Urban Heat Island in Kathmandu, Nepal: Evaluating Relationship between NDVI and LST from 2000 to 2018. *International Journal of Environment*, 8(1), 17–29. <https://doi.org/10.3126/ije.v8i1.22546>
- Othman, M., Ahrasan, N., & Thung, T. (2021). *Climate Change Impacts in Penang*. Penang Green Council.

- Piracha, A., & Chaudhary, M. T. (2022). Urban Air Pollution, Urban Heat Island and Human Health: A Review of the Literature. *Sustainability (Switzerland)*, 14(15). <https://doi.org/10.3390/su14159234>
- Rahaman, Z. A., Kafy, A. Al, Saha, M., Rahim, A. A., Almulhim, A. I., Rahaman, S. N., Fattah, M. A., Rahman, M. T., S, K., Faisal, A. Al, & Al Rakib, A. (2022). Assessing the impacts of vegetation cover loss on surface temperature, urban heat island and carbon emission in Penang city, Malaysia. *Building and Environment*, 222. <https://doi.org/10.1016/j.buildenv.2022.109335>
- Rahmani, N., & Sharifi, A. (2023). Comparative Analysis of the Surface Urban Heat Island (SUHI) Effect Based on the Local Climate Zone (LCZ) Classification Scheme for Two Japanese Cities, Hiroshima, and Sapporo. *Climate*, 11(7). <https://doi.org/10.3390/cli11070142>
- Raihan, A. (2024). A review on the role of green vegetation in improving urban environmental quality. *Eco Cities*, 4(2), 2387. <https://doi.org/10.54517/ec.v4i2.2387>
- Sha, S., & Cheng, Q. (2024). Determining the effects of green space usage on health inequalities among residents of shrinking cities based on a social capital perspective. *Urban Forestry and Urban Greening*, 97. <https://doi.org/10.1016/j.ufug.2024.128375>
- Shadman, S., Ahanaf Khalid, P., Hanafiah, M. M., Koyande, A. K., Islam, M. A., Bhuiyan, S. A., Kok, S. W., & Show, P. L. (2022). The carbon sequestration potential of urban public parks of densely populated cities to improve environmental sustainability. *Sustainable Energy Technologies and Assessments*, 52. <https://doi.org/10.1016/j.seta.2022.102064>
- Siddique, M. A., Dongyun, L., Li, P., Rasool, U., Khan, T. U., Farooqi, T. J. A., Wang, L., Fan, B., & Rasool, M. A. (2020). Assessment and simulation of land use and land cover change impacts on the land surface temperature of Chaoyang District in Beijing, China. *PeerJ*, 2020(3). <https://doi.org/10.7717/peerj.9115>
- Tan, K. C., Lim, H. S., MatJafri, M. Z., & Abdullah, K. (2010). Landsat data to evaluate urban expansion and determine land use/land cover changes in Penang Island, Malaysia. *Environmental Earth Sciences*, 60(7), 1509–1521. <https://doi.org/10.1007/s12665-009-0286-z>
- Taylor, J., Simpson, C., Brousse, O., Viitanen, A. K., & Heaviside, C. (2024). The potential of urban trees to reduce heat-related mortality in London. *Environmental Research Letters*, 19(5). <https://doi.org/10.1088/1748-9326/ad3a7e>

Received: 15th May 2026. Accepted: 6th June 2026