E-ISSN: 2948-5231

Article

Journal of Asian Geography, 2026, Volume 5 (Issue 1), 59-65
https://doi.org/10.36777/jag2026.5.1.5

Influence of Land Use Changes on the Formation of Urban Heat Island in Melaka

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Received: 15 Dec 2025; Revised: 28 Feb 2026; Accepted: 27 Mar 2026; Published: 31 Mar 2026

Abstract: This study aims to analyse the influence of land use change on the formation of the Urban Heat Island (UHI) in Melaka between 2020 and 2024. The UHI phenomenon has become increasingly evident due to rapid development and urbanisation, particularly in Melaka Tengah. Land use data were obtained from PLANMalaysia, while Land Surface Temperature (LST) data were derived from Landsat satellite imagery using the Google Earth Engine (GEE) platform. The analysis shows that built-up areas, such as buildings and urban infrastructure, contribute most significantly to the increase in surface temperature, with consistent growth in spatial extent. In contrast, forest areas, water bodies, and agricultural land have experienced noticeable reductions, thereby decreasing the natural capacity for temperature regulation. Melaka Tengah recorded the most significant UHI effect, while Alor Gajah and Jasin exhibited lower intensity due to the presence of more green and agricultural areas. This study highlights the importance of sustainable land use planning, including the expansion of urban green spaces, protection of forests and water bodies, and balanced development strategies to mitigate future UHI impacts.

Keywords: Urban Heat Island; Land Use Change; Melaka; Land Surface Temperature

1.0 Introduction

Land exploration and the utilisation of land resources constitute one of the fundamental principles underpinning human development. The exploration of land is closely associated with human existence, as it represents an effort to fulfil basic needs and demands. Land use change refers to the process whereby the original function of land is transformed into other uses due to evolving human requirements. Land use can be classified into various forms of activities, including industrial, residential, urban, and institutional uses. However, the concept and definition of land use activities often lack a uniform standard.

In Malaysia, land use activities are largely influenced by planning frameworks implemented by the Department of Town and Country Planning at the level of local authorities. Land use activities such as industrial land use may encompass small- and medium-scale industries as well as heavy and light industries. In general, land use changes occur in response to continuously evolving population demands, driven by physical, economic, and social factors.

Turner (1993), as cited in Carvalho (2006), defines land use as a process associated with human actions in modifying and adapting the land surface to meet their needs and demands. In other words, land use change is a continuous phenomenon that reflects the interaction between humans and the environment. It involves various forms of development on the land surface, including agriculture, residential areas, industrial zones, and others. In recent years, land use changes have become a critical issue in studies of global environmental change (Yong et al., 2017). Development activities inevitably exert impacts on the environment, particularly in terms of surface temperature. At present, land development and exploration are increasingly rapid, especially in regions with high population density. These human activities have contributed to the emergence of the Urban Heat Island (UHI) phenomenon (Sin and Chan, 2004; Shaharudin Ahmad et al., 2012).

Rapid land use activities have become one of the primary drivers of changes in surface temperature, particularly in urban areas. These changes are closely associated with the Urban Heat Island effect, which refers to higher surface temperatures in urban areas compared to surrounding rural regions (Oke, 1987; Khamchiaga and Dhakal, 2019; Isaac et al., 2024). Furthermore, the transformation of land use that replaces green areas with impervious surfaces such as concrete and asphalt has directly altered the surface energy balance, leading to increasingly concerning temperature conditions. This is evident in the significantly higher temperatures observed in urban areas compared to their surroundings. The Urban Heat Island observed in Melaka is therefore a direct result of rapid development and land exploration driven by human activities.

2.0 Methodology

2.1 Study Area

The state of Melaka was selected as the study area for this research. Melaka is located in the southwestern region of Peninsular Malaysia. It is a state rich in historical heritage and possesses a strategically important coastal location. Geographically, Melaka lies between 2°12′N and 102°15′E, bordering Negeri Sembilan to the north and Johor to the south. It is the second smallest state in Malaysia after Perlis, covering an area of approximately 1,664 km^2. The state comprises three main districts, namely Melaka Tengah, Jasin, and Alor Gajah (Department of Statistics Malaysia, 2023). Melaka exhibits diverse physical characteristics, including lowland areas, coastal plains, and low hills. Its coastal region, which faces the Strait of Malacca, is relatively flat and suitable for fisheries and tourism activities. St. Paul's Hill in Melaka City is one of the notable low hills with significant historical value (Yusoff et al., 2019). Melaka experiences an equatorial climate, with average temperatures ranging from 25°C to 32°C and high annual rainfall exceeding 2,000 mm. The rainy season typically occurs between October and March under the influence of the Northeast Monsoon (Tahir and Rahman, 2021).

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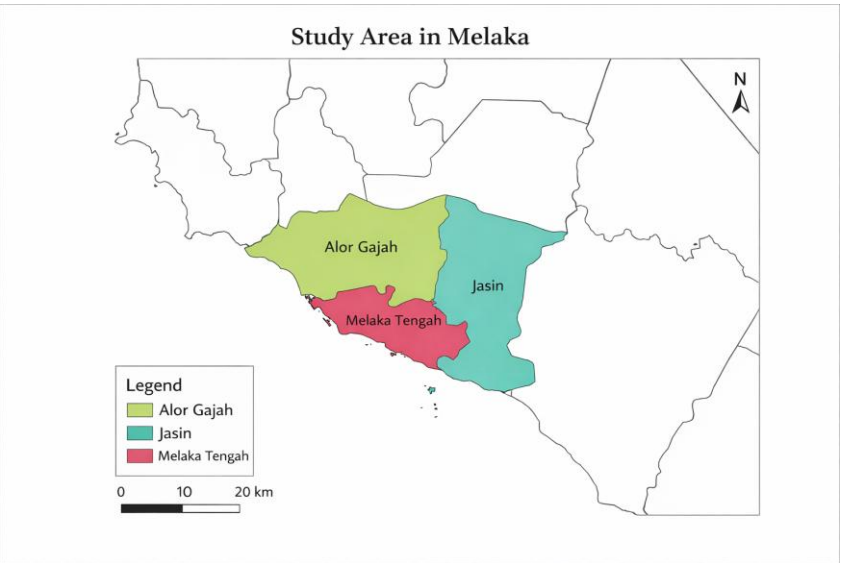


Figure 1: Study area of Melaka showing district boundaries (Alor Gajah, Jasin, and Melaka Tengah).

2.2 Land Use Change Analysis

Land use change is a key element in advancing the development and modernisation of a region. Land use characteristics determine the economic value or potential of a given area (Balasubramanian, 2006). In this study, land use maps of Melaka for five consecutive years, namely 2020, 2021, 2022, 2023, and 2024, were utilised. These maps were used to identify changes in land use classes over the study period. The land use maps obtained contained 16 categories, represented by different colour codes. However, the scope of classification was simplified into four main land use classes: built-up areas, agriculture, forest land, and water bodies. Built-up areas were used as an indicator of urbanisation in this study. Table 1 presents the four primary land use categories adopted. The land use maps for the five-year period were obtained from the IPlan Malaysia platform. To better understand land use changes in Melaka between 2020 and 2024, observational and comparative methods were applied across the five maps. Data on the area extent of each land use category were also obtained from the IPlan Malaysia Land Use Information System.

Table 1: Land Use Classes and Description

Land Use Class	Description
Built-up Area	Residential, commercial, industrial, infrastructure and utilities, institutional and community facilities, mixed development, transportation, open spaces, and recreational areas
Water Bodies	Water bodies, reservoirs, and coastal areas
Agriculture	Aquaculture, livestock farming, grassland, and mixed cropping
Forest Land	Forest areas

2.3 Urban Heat Island

Land Surface Temperature (LST) was derived from Landsat 8 Thermal Infrared Sensor (TIRS) data using the Google Earth Engine (GEE) platform. Landsat data were selected due to their appropriate spatial, spectral, and temporal resolution for analysing land use dynamics and surface thermal characteristics.

Landsat 8 Collection 2 Level-2 surface reflectance data were utilised. Cloud-contaminated pixels were removed using the Quality Assessment (QA_PIXEL) band. Annual composites for the period 2020–2024 were generated using median value compositing to minimise noise and atmospheric variability. The workflow implemented in GEE includes:

- Image filtering by date range and study area boundary
- Cloud masking using QA_PIXEL bitwise operations
- Radiometric calibration and atmospheric correction (pre-applied in Level-2 data)
- Extraction of thermal band (Band 10)
- Calculation of Land Surface Temperature (LST).

The retrieval of LST followed a standard radiative transfer approach.

(1) Conversion to Spectral Radiance

$$L_\lambda = M_L \times Q_{cal} + A_L$$

Where:

- L_λ= spectral radiance (W·m^{-2}·sr^{-1}·μm^{-1})
- M_L= radiance multiplicative scaling factor
- A_L= radiance additive scaling factor
- Q_{cal}= digital number (DN)

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(2) Conversion to Brightness Temperature (BT)

$$BT = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda}+1\right)}$$

Where:

- BT= brightness temperature (Kelvin)
- K_1, K_2= calibration constants from Landsat metadata

(3) Normalised Difference Vegetation Index (NDVI)

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

NDVI was used to estimate vegetation proportion.

(4) Proportion of Vegetation (P_v)

$$P_v = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right)^2$$

(5) Land Surface Emissivity (ε)

$$\varepsilon = 0.004 \times P_v + 0.986$$

(6) Final Land Surface Temperature (LST)

$$LST = \frac{BT}{1 + \left(\frac{\lambda \cdot BT}{\rho}\right)\ln(\varepsilon)}$$

Where:

- λ= wavelength of emitted radiance (10.895 μm for Band 10)
- $\rho = \frac{hc}{\sigma} = 1.438 \times 10^{-2}$ m\cdotpK
- h= Planck's constant
- c= speed of light
- σ= Boltzmann constant

LST values were converted from Kelvin to degrees Celsius.

The derived LST maps were clipped to the Melaka administrative boundary. Zonal statistics were applied to calculate mean LST values for each district (Melaka Tengah, Alor Gajah, and Jasin).
Urban Heat Island (UHI) intensity was assessed by comparing:

- urban (built-up dominant) areas
- rural (vegetation/agriculture dominant) areas

Land use data obtained from the IPlan Malaysia system were integrated with LST outputs to analyse spatial relationships. Overlay analysis was conducted to examine how different land use classes influence temperature distribution.
Comparative and spatial interpretation techniques were applied to identify:

- UHI hotspots
- temporal trends (2020–2024)
- relationships between land use change and thermal patterns

3.0 Results

3.1 Land Use Change

Land use change in the state of Melaka shows a gradual increase over the period from 2020 to 2024. The expansion of land use activities has contributed to rapid urbanisation across the region. This dynamic urbanisation process involves the expansion of urban-related areas and the transformation of natural physical landscapes into developed areas that generate economic value and income. These changes are evident in various aspects, including economic development, transportation networks, land use patterns, infrastructure, and overall urban growth.

Land use change in Melaka between 2020 and 2024 reveals clear and systematic transformations across four principal categories, namely built-up areas, forest, agriculture, and water bodies (Table 2). The most prominent trend is the consistent expansion of built-up areas, which increased steadily from 49,469.61 ha (29.62%) in 2020 to 52,578.70 ha (31.40%) in 2024. This growth reflects rapid urbanisation, particularly concentrated in Melaka Tengah, which functions as the administrative and economic centre of the state. The expansion of residential, commercial, and infrastructural developments is strongly linked to government-led initiatives and large-scale projects, which have accelerated spatial transformation and intensified urban land use.

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In contrast, natural and semi-natural land use categories exhibit declining or fluctuating trends. Forest areas show minor variations over time, with a temporary increase in 2022, but an overall slight decline towards 2024. Although the reduction appears modest, it indicates gradual encroachment driven by infrastructure expansion and urban development. Agricultural land, which remains the dominant land use type, demonstrates a consistent decrease throughout the study period, declining from 105,104.59 ha (62.94%) in 2020 to 103,110.40 ha (61.74%) in 2024. This trend suggests ongoing land conversion from agriculture to built-up uses, despite continued policy support for the agricultural sector.

The most significant reduction is observed in water bodies, which declined markedly from 5,952.42 ha (3.56%) in 2020 to 4,450.93 ha (2.68%) in 2024. This substantial decrease may reflect land reclamation, drainage modifications, or urban expansion into previously water-dominated areas. Overall, these patterns indicate increasing developmental pressure on natural landscapes in Melaka, highlighting the need for more sustainable land use planning strategies to balance economic growth with environmental conservation.

Table 2. Land Use Data in Melaka from 2020 to 2024 (km²)

Land Use Type	2020 (km²)	(%)	2021 (km²)	(%)	2022 (km²)	(%)	2023 (km²)	(%)	2024 (km²)	(%)
Built-up Area	494.70	29.62	501.69	30.04	521.67	31.23	523.87	31.37	525.79	31.40
Forest	64.78	3.88	64.69	3.87	69.34	4.15	68.96	4.13	67.79	4.11
Agriculture	1,051.05	62.94	1,049.13	62.82	1,033.45	61.88	1,032.12	61.80	1,031.10	61.74
Water Bodies	59.52	3.56	54.66	3.27	45.73	2.74	45.24	2.71	44.51	2.68

3.2 Urban Heat Island

The Urban Heat Island (UHI) represents an important aspect of the urban heat balance and atmospheric circulation within cities. However, this heat balance is influenced by several factors, particularly the higher air temperatures observed in urban centres compared to surrounding areas. The UHI phenomenon arises as a consequence of uncontrolled urbanisation processes (Mirzaei et al., 2012; Bokaie, 2016). Elevated temperatures in city centres and commercial districts result in urban areas being several degrees Celsius warmer than their rural surroundings (Sham, 1995; Wong et al., 2007).

The intensity of the UHI effect is closely related to urban function and city size. Its formation is strongly associated with increasing levels of urbanisation (Chan et al., 2003; Mohd. Hairy et al., 2014). Urban temperature variations are influenced by factors such as development density, city size, and surface characteristics (Mihalakakou et al., 2004). This phenomenon is often conceptualised as a “heat island”, where warmer urban areas are surrounded by relatively cooler environments.

In the context of Melaka, clear differences in land surface temperature have been observed between urban and peri-urban areas. This provides strong evidence of the presence of the Urban Heat Island phenomenon, particularly in central urban zones. The following figure presents Land Surface Temperature (LST) maps of Melaka, which were generated to further examine and understand the spatial formation of UHI across different districts within the state.

Based on the generated land surface temperature (LST) maps of Melaka, the formation of the Urban Heat Island (UHI) can be clearly observed through temperature differences across the three main districts, namely Alor Gajah, Melaka Tengah, and Jasin. There is a distinct contrast between surface temperatures in urban areas and those in surrounding peri-urban and rural zones (Figure 2). This provides clear evidence of the presence of the UHI phenomenon in Melaka, particularly within the central urban areas.

Jasin, located in the south-eastern part of Melaka and bordering the state of Johor, exhibits a relatively balanced temperature pattern characterised by lower surface temperatures. Observational analysis indicates that this district is predominantly represented by cooler colour indicators (blue and light green) throughout the five-year period from 2020 to 2024. Jasin consistently records the lowest average temperatures compared to the other districts, which can be attributed to its dominant agricultural land use and lower degree of urban development.

Alor Gajah, situated in the northern part of Melaka and bordering Negeri Sembilan, displays moderately higher temperatures than Jasin. The district is characterised by a mixture of green and yellow indicators, suggesting intermediate thermal conditions. While Alor Gajah experiences some degree of warming, its temperature levels remain lower than those observed in Melaka Tengah, reflecting a transitional landscape between rural and urban environments.

In contrast, Melaka Tengah, located in the central part of the state and adjacent to the Strait of Malacca, represents the primary urban and economic hub of Melaka. This district exhibits the highest surface temperatures, as evidenced by the dominance of red indicators across most areas throughout the study period from 2020 to 2024. The concentration of built-up areas, dense infrastructure, and intense human activity contributes significantly to the pronounced UHI effect observed in this district. These findings confirm that Melaka Tengah is the most thermally affected region in the state.

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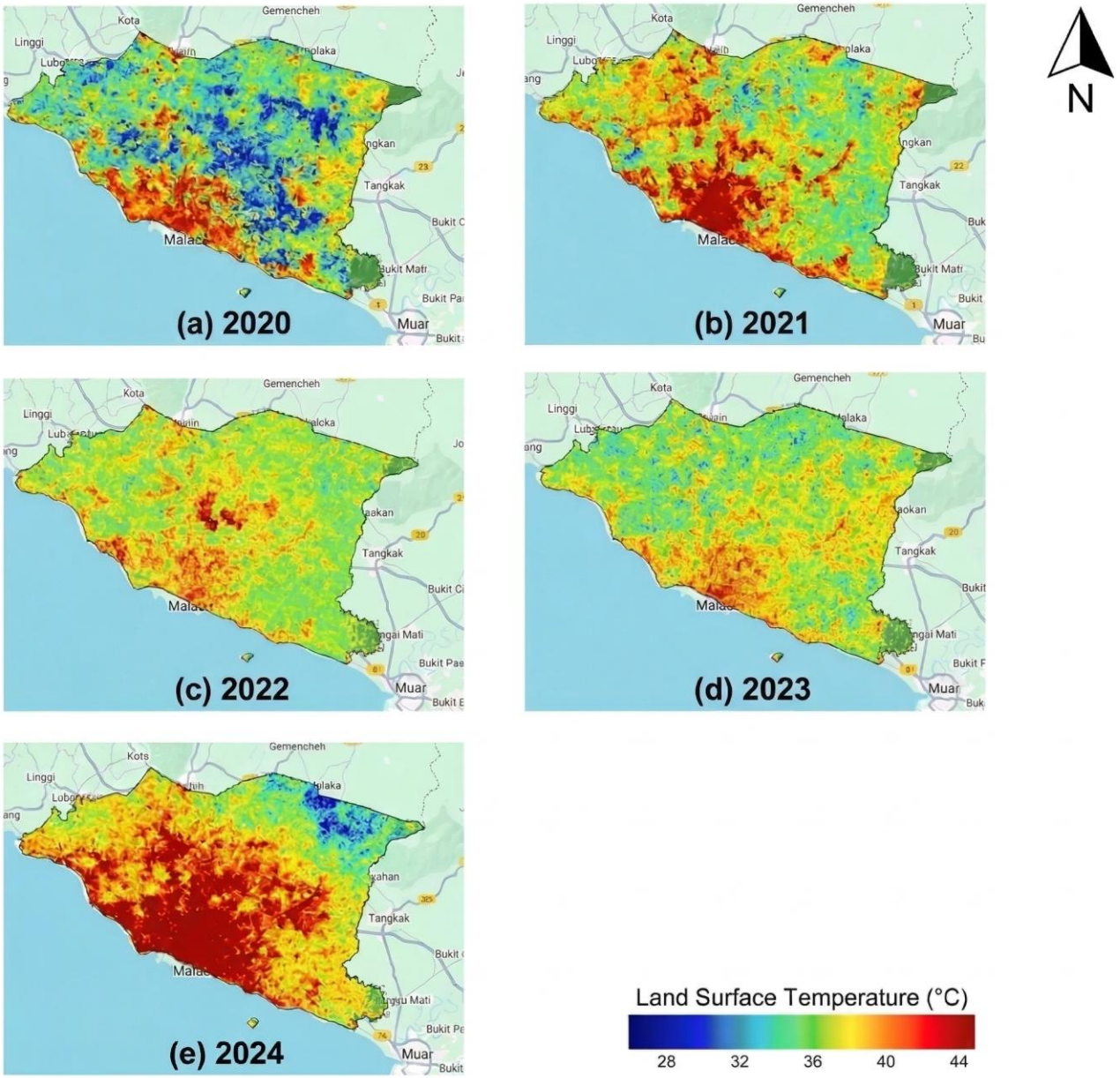


Figure 2: Spatial distribution of Land Surface Temperature (LST) in Melaka from 2020 to 2024. Source: Derived from Landsat 8 imagery using Google Earth Engine.

4.0 Discussion

4.1 Land Use Influence on Urban Heat Island

The analysis of land use and land surface temperature (LST) reveals a clear relationship between land use types and the spatial distribution of temperature, which contributes directly to the formation of the Urban Heat Island (UHI) in Melaka. Variations in average surface temperature across the three main districts, namely Jasin, Alor Gajah, and Melaka Tengah, can be explained by differences in dominant land use patterns. Areas with a higher proportion of built-up land tend to exhibit elevated temperatures, whereas regions dominated by agricultural and vegetated land show relatively lower thermal values.

Jasin consistently records the lowest surface temperatures, which can be attributed to its predominantly agricultural land use and relatively limited urban development. Agricultural land occupies a substantial proportion of the district, providing cooling effects through evapotranspiration and reduced heat absorption compared to impervious surfaces. In contrast, Alor Gajah demonstrates moderate thermal characteristics, reflecting a transitional landscape where agricultural land remains dominant but is increasingly complemented by residential and infrastructural development. This mixed land use structure results in intermediate surface temperatures between the cooler conditions of Jasin and the more intense heat observed in Melaka Tengah.

Melaka Tengah exhibits the highest surface temperatures and the most pronounced UHI effect, driven by extensive urban development. The concentration of built-up areas, including residential, commercial, industrial, and infrastructural land uses, has significantly altered the surface energy balance. Materials such as concrete and asphalt possess high heat storage capacity, absorbing solar radiation during

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the day and releasing heat at night, thereby intensifying urban temperatures. Rapid population growth, increased economic activity, and infrastructure expansion further contribute to the density of development, reinforcing the UHI effect in this district.

Among the various land use categories, built-up areas exert the strongest influence on UHI formation. Their expansion between 2020 and 2024 has increased the extent of heat-retaining surfaces while simultaneously reducing natural cooling elements such as vegetation and open spaces. Conversely, forested areas and water bodies play a critical role in moderating temperature through shading, evapotranspiration, and evaporative cooling processes. However, the gradual reduction of these natural land covers has weakened their capacity to regulate local thermal conditions. Agricultural land, although less effective than forests in cooling, still contributes to maintaining lower temperatures compared to urban surfaces. The continued conversion of agricultural land into built-up areas therefore represents a key driver of increasing surface temperature in Melaka.

Overall, the findings demonstrate that the interaction between land use change and anthropogenic heat generation is central to the development of the UHI phenomenon in Melaka. The dominance of built-up land, particularly in Melaka Tengah, has intensified thermal conditions, while the reduction of vegetation and water bodies has diminished the natural capacity for temperature regulation. These results highlight the importance of integrating sustainable land use planning and urban design strategies to mitigate the impacts of UHI and promote a more balanced urban environment.

4.2 Mitigation Strategies

The increasing intensity of the Urban Heat Island (UHI) effect in Melaka highlights the urgent need for effective mitigation strategies that integrate urban planning, environmental management, and sustainable development principles. The findings of this study indicate that the expansion of built-up areas, particularly in Melaka Tengah, has significantly altered the thermal environment. As such, targeted interventions are required to reduce surface temperatures and enhance urban liveability.

One of the most effective mitigation strategies is the implementation of green roofing systems. Green roofs, which involve the incorporation of vegetation layers on building rooftops, can significantly reduce heat absorption by providing insulation and promoting evapotranspiration. This approach not only lowers surface temperatures but also improves stormwater management and air quality. Empirical studies have shown that green roofs can reduce surface temperatures by up to 10°C in urban environments, demonstrating their potential applicability in Melaka. The adoption of green roofing could be encouraged through policy incentives and technical guidelines provided by local authorities, thereby promoting its integration into both new and existing developments.

In addition, urban greening through tree planting and the expansion of green spaces plays a crucial role in mitigating UHI effects. Vegetation contributes to cooling through shading and evapotranspiration, reducing ambient temperatures and improving microclimatic conditions. Increasing tree cover along streets, within residential areas, and in public spaces such as parks can significantly lower surface temperatures. Studies suggest that urban greenery can reduce temperatures by approximately 2°C to 4°C, particularly in tropical environments. In Melaka, priority should be given to highly urbanised areas such as Melaka Tengah, where the lack of vegetation exacerbates heat accumulation. Community-based greening initiatives and the development of green corridors can further enhance the effectiveness of this strategy.

The use of reflective and high-albedo construction materials also represents an important approach to reducing urban heat. Conventional materials such as asphalt and concrete tend to absorb and retain large amounts of solar radiation, contributing to elevated surface temperatures. In contrast, reflective materials, including light-coloured roofing, cool pavements, and high-albedo coatings, can reduce heat absorption and enhance thermal comfort. Research indicates that such materials can lower surface temperatures by approximately 1°C to 3°C. The implementation of these materials in road infrastructure and building construction should be supported through regulatory measures and financial incentives to encourage widespread adoption.

Finally, effective urban planning and zoning policies are essential for long-term UHI mitigation. Balanced land use planning that incorporates adequate green spaces within residential, commercial, and industrial zones can help regulate urban temperatures. The establishment of green zoning principles, including minimum green space requirements and the preservation of natural landscapes, is critical in preventing excessive urban heat accumulation. Additionally, the integration of cooling elements such as urban parks, artificial lakes, and open spaces within densely built environments can further enhance thermal regulation. Strategic planning that limits overdevelopment in peri-urban areas such as Jasin and Alor Gajah will also help maintain ecological balance and reduce the spatial expansion of UHI effects.

Overall, mitigating the UHI phenomenon in Melaka requires a comprehensive and integrated approach that combines technological solutions, ecological interventions, and policy-driven planning strategies. These measures are essential to ensure sustainable urban development while maintaining environmental quality and improving the thermal comfort of urban populations.

5.0 Conclusions

The study presented in this report provides several important findings regarding urban climate phenomena, particularly the Urban Heat Island (UHI) effect and its influencing factors. Based on the analysis and observations conducted, several key conclusions can be drawn to provide a comprehensive understanding of the research outcomes.

First, the findings indicate that the UHI phenomenon is a significant reality in urban areas, especially in regions experiencing rapid development and high population density, such as Melaka Tengah. Surface temperatures in Melaka Tengah are notably higher than those in surrounding rural areas, primarily due to heat accumulation from impervious surfaces such as roads, concrete structures, and asphalt. This condition is further exacerbated by the limited presence of green spaces and vegetation, which would otherwise contribute to cooling through evapotranspiration. The UHI effect not only influences surface temperature but also increases ambient air temperature, thereby contributing to greater thermal discomfort among urban residents.

Second, the study identifies several key factors influencing the intensity of UHI, including land use type, urban design, and patterns of human activity. Areas dominated by high-rise buildings and extensive road networks exhibit more pronounced UHI effects compared to low-density residential areas with greater vegetation cover. As demonstrated in this study, the central urban areas of Melaka Tengah record the highest average surface temperatures among all districts, reinforcing the conclusion that UHI is an inherent challenge associated with urban development.

Third, the study highlights several mitigation strategies to reduce the impact of UHI. These include increasing urban tree planting, developing public green spaces, and adopting heat-reflective construction materials such as cool roofs and light-coloured pavements. The implementation of sustainable urban development principles and green city design is emphasised as a long-term strategy for mitigating UHI effects. In addition, community involvement, such as awareness campaigns promoting tree planting and energy conservation, is identified as a critical component in addressing this issue.

In conclusion, this study underscores the importance of understanding and addressing the Urban Heat Island phenomenon as part of broader efforts towards sustainable urban development. The findings provide not only a clear explanation of the contributing factors and

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impacts of UHI but also a practical foundation for mitigation strategies. While the results are directly relevant to Melaka, they also offer valuable insights for other regions facing similar challenges due to rapid urbanisation. A holistic and integrated land use planning approach is essential to ensure sustainable development that balances economic growth, social well-being, and environmental sustainability. With strong commitment and collaboration among stakeholders, the impacts of UHI can be mitigated, thereby enhancing the quality of life for present and future generations.

Acknowledgement: Thanks to editors and reviewers for their constructive comments.

Data Availability: The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Conceptualisation: A. K. E. D. Sham; Methodology: A. K. E. D. Sham and M. A. Mahamud; Literature search: A. K. E. D. Sham; Data analysis: A. K. E. D. Sham; Writing – original draft: A. K. E. D. Sham; Writing – review and editing: M. A. Mahamud; Critical review: M. A. Mahamud; Supervision: M. A. Mahamud; Final approval: A. K. E. D. Sham and M. A. Mahamud.

Conflicts of Interest: The author declares that there is no conflict of interest.

Ethics Statement: Ethical approval was not required as the study involved no human participants or identifiable personal data.

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