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# A Geospatial Exploration of Surface Urban Heat Dynamics and Predictive Modeling in Kandy Municipal Council Using GIS and RS Techniques

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## Abstract

This research, conducted in the Kandy MC area, addresses critical research gaps pertaining to urban temperature in mountainous regions. Bridging existing knowledge with current data, the study highlights a notable increase in maximum temperature from 31 °C in 2013 to 38°C in 2023, underscoring a significant 7°C rise. A unique observation reveals Deiyannewela consistently registering the highest temperature across all three time points. The research delves into the correlation dynamics, establishing a negative relationship between LST, NDWI and NDVI, while showcasing a positive correlation with the NDBI. Factoring in these correlations, the projected urban temperature for 2033 indicates a range of 32.88 to 41.2 degrees Celsius, reflecting a 3.2 °C increase from 2023.This temperature escalation underscores the urgent need for sustainable urbanization. The study advocates immediate measures to mitigate rising temperatures, emphasizing the incorporation of green spaces into future urban development strategies. In conclusion, the challenge of escalating surface temperatures in Kandy MC demands a comprehensive, multidimensional approach that integrates geographical insights with sustainable development practices. Drawing insights from Landsat 8, renowned for its 30m high resolution and spectral compatibility with MODIS data, this research spans 2013, 2018, and 2023, utilizing Landsat 8 imagery to calculate key indices such as LST, NDVI, NDWI, and NDBI. These findings offer a nuanced understanding of the temperature dynamics in the region, providing essential guidance for well-informed urban planning and laying the groundwork for climate-sensitive and sustainable development in rapidly urbanizing mountain cities like Kandy.

**Key words:** Land Surface Temperature (LST), Landsat 8, Correlation, Sustainable Development, Kandy MC

## 1. Introduction

In an era marked by unprecedented urbanization trends, the United Nations forecasts a monumental shift, projecting that by 2030, 60% of the global population will be concentrated in urban areas (Chun et al., 2014). This impending surge in urbanization raises multiple of challenges for both the environment and the well-being of urban residents. The anticipated rise in the urban population is poised to amplify daily traffic, creating a symbiotic

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relationship with an associated increase in greenhouse gas emissions, thereby posing a substantial threat to global efforts aimed at mitigating climate change (UNEP 2024).

The expansion of urban areas, an inevitable consequence of accommodating the growing populace, unfurls a series of adverse effects on the geographical landscape. The proliferation of built-up areas, while catering to burgeoning urban populations, concurrently contributes to a reduction in green spaces — integral components for maintaining environmental balance. These green spaces, ranging from parks to forests, serve as crucial carbon sinks and bastions of biodiversity. However, the diminishing green spaces exacerbate the urban heat island effect, leading to localized increases in land surface temperatures, and presenting a complex challenge at the intersection of urban development and environmental sustainability (GSFC-NASA 2024).

Simultaneously, the reduction in areas capable of storing water accentuates the risk of water scarcity in urban environments. Surfaces dominated by concrete and asphalt, prevalent in built-up areas, prove inefficient in absorbing water, resulting in increased runoff and diminished groundwater recharge. This situation further intensifies the prominence of urban heat islands, contributing to heightened vulnerability to extreme weather events, underscoring the intricate web of challenges that urbanization weaves on the geographical and climatic fabric (Olivadese et el., 2024).

Geographically, these consequences are manifested in diverse ways, with regions undergoing rapid urbanization witnessing transformative shifts in landscapes. Expanding urban sprawl encroaches upon natural habitats, heralding irreversible alterations in local ecosystems, biodiversity, and the overall resilience of the landscape. The strong correlation observed between built-up areas, vegetation cover, and the reduction of water storage space paints a vivid picture of the inevitable increase in land surface temperature (Feng et al.,2017). This correlation, embedded in the fabric of urbanization challenges, underscores the imperative need for comprehensive strategies in urban planning, echoing the urgent call for environmental sustainability and climate resilience.

While global urbanization trends unfold on a grand scale, the mountain cities across Asia stand as witness to significant development during the 19th and 20th centuries, characterized by urbanization and growth (Ranagalage, 2018). Amidst the general understanding that temperatures decrease with higher elevation, the case of Kandy city in Sri Lanka presents a unique anomaly. Despite its distinctive geographical features, the temperature in Kandy exhibits a contrary trend, arousing curiosity and prompting a closer examination into the complex interplay of geographical and anthropogenic factors influencing local climate dynamics.

The curiosity surrounding this unusual phenomenon forms the backdrop of a research endeavor aimed at unraveling the intricacies of temperature dynamics in Kandy city. As urbanization continues to reshape the cityscape, understanding the factors contributing to the unexpected temperature rise becomes imperative for sustainable development and climate resilience in this hilly terrain of central Sri Lanka. Kandy, boasting a terrain that would conventionally be associated with cooler temperatures, unfolds as a case study to investigate the nuanced interplay between geographical and anthropogenic elements influencing local climate dynamics.

The primary objective of this research is to forecast the expected temperature in the Kandy Municipal Council by the year 2033. This forward-looking projection serves as a crucial step in developing proactive strategies to mitigate potential adverse impacts on the city's climate. By identifying the factors contributing to the temperature anomaly and anticipating future trends, this study aspires to provide actionable insights for policymakers and urban planners, offering a roadmap for sustainable urban development and climate-resilient practices in the unique topography of Kandy.

The urbanization wave that has swept through the past decade, leaving behind a trail of significant negative impacts, finds echoes in the urban landscapes of other mountainous cities across Asia. Baguio in the Philippines, Dalat in Vietnam, Pyin Oo Lwin in Bogor in Indonesia, and Kathmandu in Nepal have all emerged as major focal points grappling with the repercussions of rapid urbanization, much akin to the challenges faced (Estoque et al.,2016, Estoque et al 2012., Estoque et al 2011). Ranagalage et al 2018, points out that Kandy city, within the last decade, has joined the ranks of hilly cities undergoing rapid urbanization, further underscoring the need for meticulous research into the complex dynamics of temperature trends in mountainous urban environments.

In the realm of scientific inquiry, Remote Sensing (RS) datasets emerge as crucial tools for calculating Land Surface Temperature (LST). These datasets incorporate the relevant variables necessary to determine the radiation load on the Earth's surface (Almeida et al.,2021). Landsat 8 data, with its high spatial resolution of 30m and two Thermal Infrared (TIR) channels akin to MODIS data, takes center stage as a key data source (Zhang et al.,2019) in this study. The years 2013, 2014, and 2023 have been meticulously chosen as the temporal window for analysis, offering a comprehensive examination of the evolution of temperature dynamics.

Researchers in this field accentuate the significance of impervious surfaces and green spaces in influencing LST calculations (Simwanda 2019). Impervious surfaces, characterized by materials resistant to water infiltration, contribute to higher temperatures, while green spaces act as cool zones, mitigating heat. To delve deeper into these dynamics, the correlation between LST and the Normalized Difference Water Index (NDWI) takes center stage in the examination. This critical analysis identifies NDWI as a pivotal factor, providing insights for planning a more sustainable ecosystem through long-term exploration, particularly when considering the nuanced variations in land surfaces across seasons (Guha et al.,2021).

In conclusion, the interconnected narratives of global urbanization trends, the unique challenges posed by mountain cities in Asia, and the localized anomaly in temperature dynamics in Kandy city form the rich tapestry of this research paper. As we navigate the intricate intersections of urbanization, climate dynamics, and environmental sustainability, each thread contributes to a holistic understanding of the complex fabric woven by human activities and their repercussions on the planet. The research endeavors outlined herein not only seek to unravel the intricacies of these phenomena but also aspire to provide actionable insights for forging a path towards a more resilient and sustainable future.

## 2. Materials and Methods

### *2.1 Study area*

The city of Kandy, recognized as the second-largest city in Sri Lanka (Ranagalage et al,2018), is situated at approximately 70 21' degrees North latitude and 80 45' degrees East longitude (Resource profile Gangawata korale DSD,2022). Nestled within the picturesque Mahaweli Valley, Kandy finds itself flanked by the majestic Mahaweli River to the Northeast and West, while the Southern border is defined by the impressive Hantana range. The Kandy Municipality encompasses an expansive land area of 2,645 hectares, forming a distinctive triangular shape (Uduporuwa,2020).

Kandy's topography is marked by the convergence of three valleys, creating the inner city located at an elevation of 1600 feet within a compact 0.4-mile basin. This unique geographical setting contributes to the city's charm and character. In 1979, Kandy was designated as an urban development area(uda.gov.lk), underscoring its significance in the region. Subsequently, in 1988, the city earned the prestigious title of a World Heritage City by UNESCO, recognizing its cultural and historical importance.

The climate in Kandy is characterized by an average annual temperature of 25.6 degrees Celsius, providing residents and visitors with a pleasant and moderate environment. The city also experiences an annual rainfall of 1543 mm (Resource profile Gangawata korale DSD,2022), contributing to the lush greenery and vibrant landscapes that add to Kandy's allure. The convergence of natural beauty, historical significance, and cultural richness makes Kandy a truly remarkable destination in Sri Lanka.

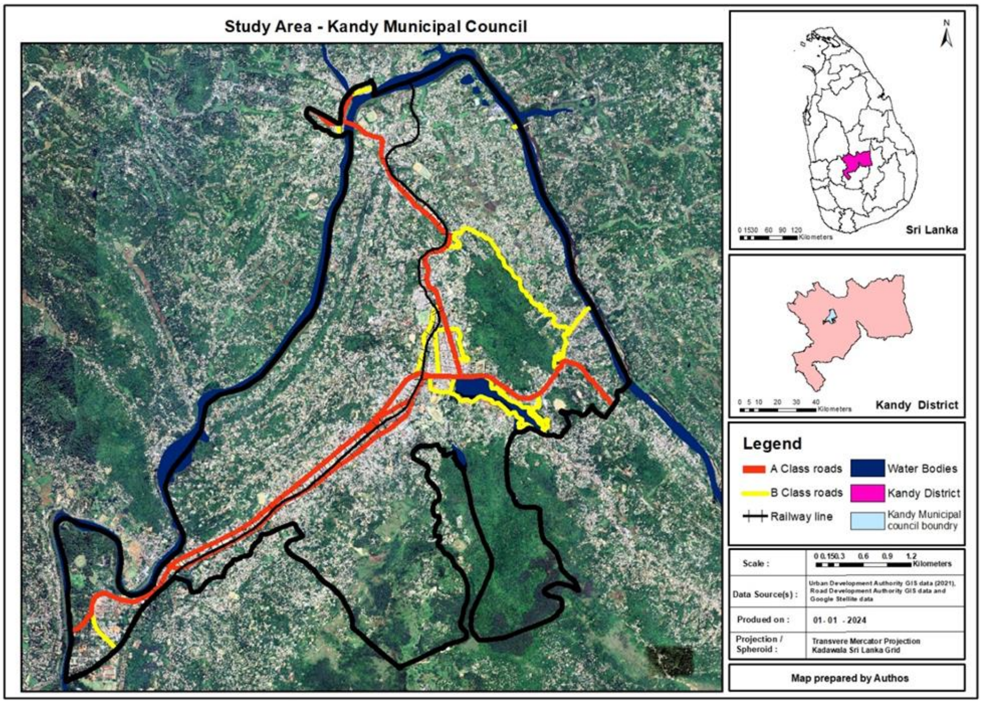

Figure 1 : Study area
Source: Urban Development Authority, 2021, Road Development Authority, and Google satellite data

## *2.2 Data Description and pre – Processing*

In the study, Landsat-8 OLI/TIRS satellite imagery acquired during the dry seasons on August 30, 2013, February 17, 2018, and February 15, 2023, was utilized. The Landsat-8 data included multispectral bands (bands 1 to 7 and 9) with a spatial resolution of 30 meters. Additionally, the panchromatic band (band 8) had a higher spatial resolution of 15 meters, while the thermal bands (band 10 and 11) originally had a spatial resolution of 100 meters. However, the thermal bands were resampled to 30 meters by the USGS (http://landsat.usgs.gov).

The selection process ensured the use of cloud-free images, with a strict criterion of <=10% cloud cover. This is crucial for obtaining reliable and clear data for subsequent analysis. The selected satellite images were then mapped using the WGS84/UTM44N projection, providing a georeferenced representation of the study area.

To enhance the accuracy of subsequent analyses, the projected images underwent radiometric calibration and atmospheric correction using GIS software. During this correction process, the Digital Number (DN) values of the multispectral bands were adjusted. Additionally, the DN values of the thermal bands were converted into atmospheric brightness temperature in degrees Kelvin (Ranagalage et al.,2017).

With the pre-processed images, the study focused on extracting key biophysical parameters for the Kandy Municipal Council (MC). Specifically, Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), and Normalized Difference Built-up Index (NDBI) were derived. These parameters are essential for understanding the thermal characteristics, vegetation health, and built-up areas in the geographic region of Kandy MC.

Kandy MC encompasses a specific area that was systematically analyzed using the extracted LST, NDVI, and NDBI values. This comprehensive approach provides valuable insights into the land surface dynamics, vegetation cover, and urbanization patterns within the study area over the specified time periods.

Table 1: Descriptions of the Landsat images

| Sensor | Scene ID | Acquisition Data | Time (GMT) | Season |
|---|---|---|---|---|
| **Landsat 8 OLI/TIRS** | LC81410552013242LGN01 | 30 - 08 - 2013 | 4.55.58 | Dry |
| **Landsat 8 OLI/TIRS** | LC81410552013242LGN00 | 17 - 02 - 2018 | 4.53.43 | Dry |
| **Landsat 8 OLI/TIRS** | LC81410552013242LGN00 | 15 - 02 - 2023 | 4.54.11 | Dry |

Source: Landsat 8 satellite data

### *2.2.1 Land Surface Temperature (LST) Estimations*

Land Surface Temperature (LST) estimation is a crucial aspect of remote sensing, often derived from satellite imagery captured in different spectral bands. In this context, Bands 4, 5, and 10 refer to specific wavelengths recorded by the satellite sensor. Band 4 usually captures red light, Band 5 captures near-infrared, and Band 10 records thermal infrared (http://landsat.usgs.gov). Combining these bands allows us to estimate LST using a systematic approach.

Once the brightness temperature is determined, conversion to Land Surface Temperature is facilitated through a series of calibration and correction factors. Atmospheric conditions must also be considered, necessitating the implementation of suitable correction techniques. This ensures that the LST values are reflective of the true surface temperature, uncontaminated by atmospheric effects.

The estimation of Land Surface Temperature from Bands 4, 5, and 10 involves a multi-step process. Leveraging the unique characteristics of each band, applying the addressing atmospheric influences, and incorporating calibration procedures collectively contribute to the accurate derivation of LST. Through meticulous documentation and validation, the reliability of the results is heightened, facilitating meaningful insights into surface temperature dynamics.

i. Conversion to TOA Reflectance

The first step is to input band 10 into ArcGIS software. then TOA can be obtained using the following equation;(Avdan et al.,2016) (www.usgs.gov)

$$L\lambda = M\_L * Q\_Cal + A\_L - Qi \quad (1)$$

When,

ML represent – Band specific multiplicative rescaling factor

Qcal represent – Band 10

AL represent – Band specific additive rescaling factor

Qi represents – Correction band 10

Table 2 : TOA Calculation Metadata

| | |
|---|---|
| **$M_L$** | 0.000334 |
| **$A_L$** | 0.1 |
| **$Q_i$** | 0.29 |

Source: Landsat 8 satellite data

*Note – This can be obtained from the MLT file, there

ML – RADIANCE_MULT_BAND_10

AL – RADIANCE_ADD_BAND_10

ii. Conversion to Brightness Temperature (BT)

In the second step, the values should be converted from spectral radiance to brightness temperature, for which the following equation was used (Avdan.,2016) (www.usgs.gov).

$$BT = \frac{k_2}{Ln[(k_1 \,/\, L\lambda) + 1]} - 273.15 \tag{2}$$

When,

Lλ represent – TOA spectral radiance

$K_1$ represent – Band specific thermal conversion constant from the metadata

$K_2$ represent - Band specific thermal conversion constant from the metadata

Figure 2 :BT Calculation Metadata

| | |
|---|---|
| **$K_1$** | 774.8853 |
| **$K_2$** | 1321.0789 |

Source: Landsat 8 satellite data

*Note – This can be obtained from the MLT file, there

$K_1$ and $K_2$ –CONSTANT_BAND_10

To obtain results in Celsius, the radiant temperature is adjusted by incorporating the absolute zero offset of approximately -273.15°C.

iii. Calculation of Normalized Difference Vegetation Index (NDVI)

The calculation of Normalized Difference Vegetation Index (NDVI) involves the utilization of both the red (band 5) and near-infrared bands (band 4) (Almeida et al.,2021). NDVI serves as a pivotal variable in the context of monitoring urban climate conditions, offering valuable insights into vegetation health and land cover changes within urban areas (Rangalage et al.,2018). By comparing the reflectance of vegetation in the red and near-infrared spectral regions, NDVI provides a quantitative measure that can be instrumental in assessing urban greenery, heat island effects, and overall environmental dynamics (Gallo et al.,1993). NDVI can be obtained using the following equation;(Uduporuwa and Manawadu.,2017).

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{3}$$

iv. Calculating the proportion of vegetation (PV)

Proportion of Vegetation (PV) is a measure that quantifies the proportion of vegetation covering an area by comparing the vertical projection of plants on the ground to the total area occupied by vegetation (Deardorff,1978). PV provides insight into how much of the ground surface is effectively covered by the vertical projection of the plants, giving an indication of the density or extent of vegetation in a given area.

$$pv = \left[\frac{(NDVI - NDV\,Im\,in)}{(NDV\,I\,m\,ax + NDV\,Im\,in)}\right] \tag{4}$$

v. Calculating the Land Surface Emissivity (LSE)

To estimate Land Surface Temperature (LST), Knowledge of Land Surface Emissivity (LSE) is crucial (Avdan et al.,2016), and it can be obtained using the following equation (Gelata et al.,2023)

$$E = 0.004 \times pv + 0.986 \tag{5}$$

vi. Calculating The Land Surface Temperature (LST)

The last step to get LST is to do the calculation as follows (Avdan et al.,2016, Rangalage et al.,2017).

$$LST = \frac{BT}{\{1 + [(\lambda \times BT/\rho)InE]\}} \tag{6}$$

When,

BT represent – Brightness Temperature

$\lambda$ represent – Wavelength of emitted radiance

$\rho$ represent – Correspond to 1.438 * 10-2

E represent - Land Surface Emissivity

Table 3: LST Calculation Metadata

| | |
|---|---|
| $\boldsymbol{\lambda}$ | 0.00115 |
| $\boldsymbol{\rho}$ | 1.4388 |

Source: Landsat 8 satellite data

### *2.2.2 Normalized Vegetation Index (NDVI) Estimations*

The Normalized Difference Vegetation Index (NDVI) is extensively employed in land surface temperature calculations, providing valuable insights into vegetation health and influencing temperature dynamics (Chun et al. ,2014). The calculation of NDVI involves the utilization of both the red and near-infrared bands (Avdan.,2016).

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{7}$$

When,

NIR represent – Band 5

Red represents – Band 4

### *2.2.3 Normalized Difference Built – up Index (NDBI) Estimations*

Calculating the Normalized Difference Built-Up Index (NDBI) facilitates the identification and classification of built-up areas or polluted surfaces (Zha et al.,2003). High NDBI values indicate built-up areas, while values close to zero signify the presence of vegetation. Additionally, NDBI values appearing in the negative values are indicative of water bodies(liu,2017). The calculation of NDBI involves the utilization of both the red and near-infrared bands (https://pro.arcgis.com/en/pro-app/latest/arcpy/spatial-analyst/ndbi.htm - NDBI-ArcGIS pro Documentation).

$$NDBI = \frac{SWIR - NIR}{SWIR + NIR} \tag{8}$$

When,

SWIR represent – Band 6

NIR represent – Band 5

### *2.2.4 Normalized Difference Water Index (NDWI) Estimations*

Normalized Difference Water Index (NDWI) is a spectral index commonly employed in remote sensing to discern the presence and characteristics of bodies of water. It operates on the principle that areas with abundant water exhibit distinctive spectral signatures, allowing for their differentiation from dry or non-aqueous regions. In the NDWI scale, values close to +1 signify regions with elevated water content, indicating the likely presence of water bodies. On the other hand, values approaching -1 suggest dry or drought conditions, as these areas exhibit a low water content (Eco data analytics, https://eos.com/). The calculation of NDWI involves the utilization of both the red and Short -Wave infrared bands (Kshetri.,2018).

$$NDWI = \frac{NIR - SWIR}{NIR + SWIR} \tag{9}$$

When,

NIR represent – Band 5

SWIR represent – Band 6

### *2.2.5 Deriving the Equation to Calculate the Expected Temperature in 2033*

The pivotal research paper, "Projecting of Land Surface Temperatures Considering the Effects of Future Land Changes at the Tihu Lake Basin of China" stands as a cornerstone in the estimation of expected temperatures for the year 2033. The study area, distinguished by its annular shape and incorporation of forest cover, exhibits striking similarities with the physical characteristics of Kandy city limits. The topography unfolds in a basin-like configuration, adorned with expansive forested areas, thereby underscoring the pertinence of applying the same equations within the context of Kandy. This seamless alignment in both geographical features and modeling strategies fortifies the reliability and applicability of the equations derived from the Tihu Lake Base study to forecast temperatures in the specific and analogous terrain of Kandy.

For this study, the years 1996, 2004, and 2016 have been selected for comprehensive analysis, mirroring the temporal considerations of the referenced research. By utilizing the CA-Markov module of the IDRISI software, researchers have successfully computed the projected temperature for the year 2026. The equation derived from this model,

$$LST = 33.48 + 8.66NDBI + 2.9NDVI - 4.011NDWI + 13.34NDBI * NDVI \tag{10}$$

with a value of 33.48 representing the highest temperature in the year 2016, encapsulates collaborative efforts aimed at modeling temperature projections. The additional values in the equation are meticulously obtained through the CA-Markov model, ensuring a comprehensive and accurate representation of the temperature dynamics.

Building upon this established foundation, the primary objective of the experiment is to forecast the temperature for Kandy Municipal Council in the year 2033, employing a similar equation structure.

$$LST = 37.68 + 8.66NDBI + 2.9NDVI - 4.011NDWI + 13.34NDBI * NDVI \quad (11)$$

When,

37.68 = Highest temperature value in 2023

## 3. Results

### *3.1 LST in 2013, 2018 and 2023*

The LST map of the KMC area reveals dynamic temperature variations over the years (figure 4). In 2013 Aguste 30(4.55.58GMT), LST values ranged from 21o C to 31 o C, with a mean LST value of 25.51 o C. Notably, the Deiyannewela Grama Niladari Division reported the highest temperatures (28 o C -31 o C) among the 37 surveyed GNDs. Moving to 2018 February 17(4.53.43GMT), the LST range expanded to 21 o C -34 o C, with a mean of 26.72 o C. Remarkably, there was a 3°C growth in the highest LST value in the Deiyannewela division by August 30.

The 2018 February 17 (4.53.43GMT) exhibited fluctuations in LST values, particularly in the Senkadagala Grama Niladari Division, where temperatures increased by 9°C from the 21°C -25°C range. By 2023 February 15(4.54.11GMT), LST values ranged from 23°C to 38°C, with a mean of 29.56°C. The Grama Niladari Division of Deiyannewela and Mahanuwara recorded the highest LST values (23°C -38°C), signaling a 4°C increase compared to 2018 February 17(4.53.43GMT). The Senkadagala Grama Niladari Division also showed a 1° C increase.

Geographically, the LST dynamics from 2013 Agust 30 (4.55.58GMT) to 2023 February 15 (4.54.11GMT) depict a fluctuation of 7°C across the KMC area. This spatial-temporal variability highlights the intricate patterns of land surface temperatures, emphasizing the importance of considering both time and geography in understanding climate trends.

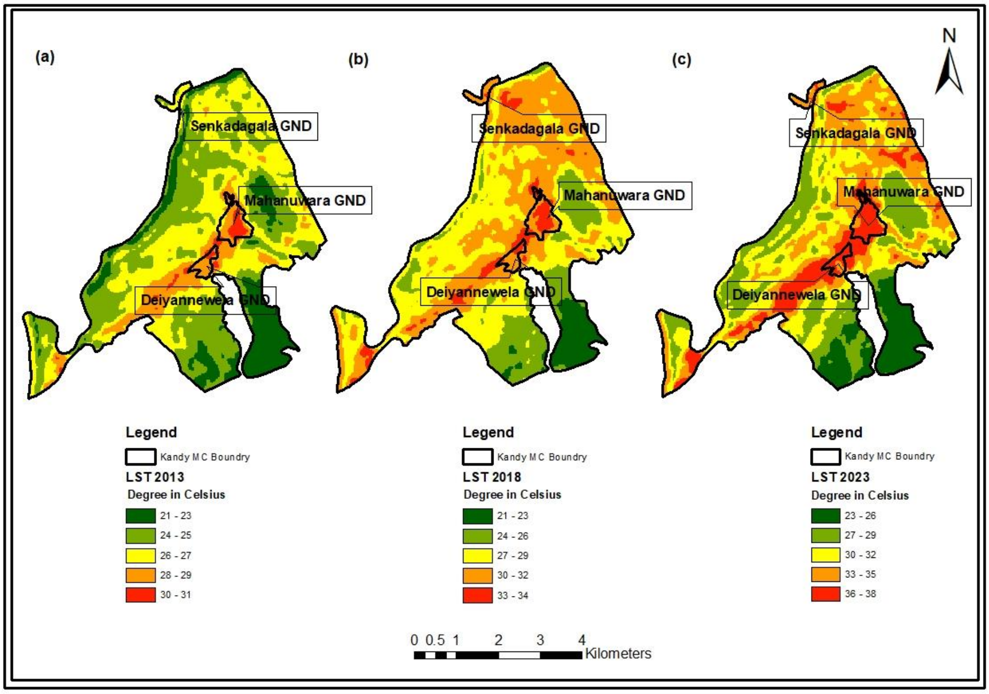

Figure 4 : Land Surface Temperature (LST) maps of KMC
Source: 1:50000 digital data and Google satellite data

### *3.2 NDVI in 2013, 2018 and 2023*

Figure 3 illustrates the NDVI maps for the years 2013, 2018, and 2023 in the KMC area, offering insights into vegetation dynamics. In 2013, NDVI values ranged from -0.1 to 0.6, with a mean of 0.25. High vegetation density cover was noticeable towards the East and Southeast of the KMC. In 2018, NDVI values varied from -0.1 to 0.6, with a mean of 0.25. A distinct low vegetation density cover (0.07 - 0.2) was observed towards the center of the city.

Examining the NDVI values for 2023, a range of -0.2 to 0.6 was identified, with a mean of 0.2. Notably, compared to 2013, there was a significant decrease in high-density vegetation cover in the East and Southeast directions. Moreover, in 2018, there was a lack of vegetation density in the middle of the city, but by 2023, a positive increase in vegetation density can be identified.

Geographically, these changes highlight the spatial dynamics of vegetation cover over the three time points. The east and southeast areas experienced a decline in high-density vegetation cover by 2023, while positive changes were observed in the city center. This spatial-temporal analysis provides valuable insights into the evolving patterns of vegetation density in the KMC area.

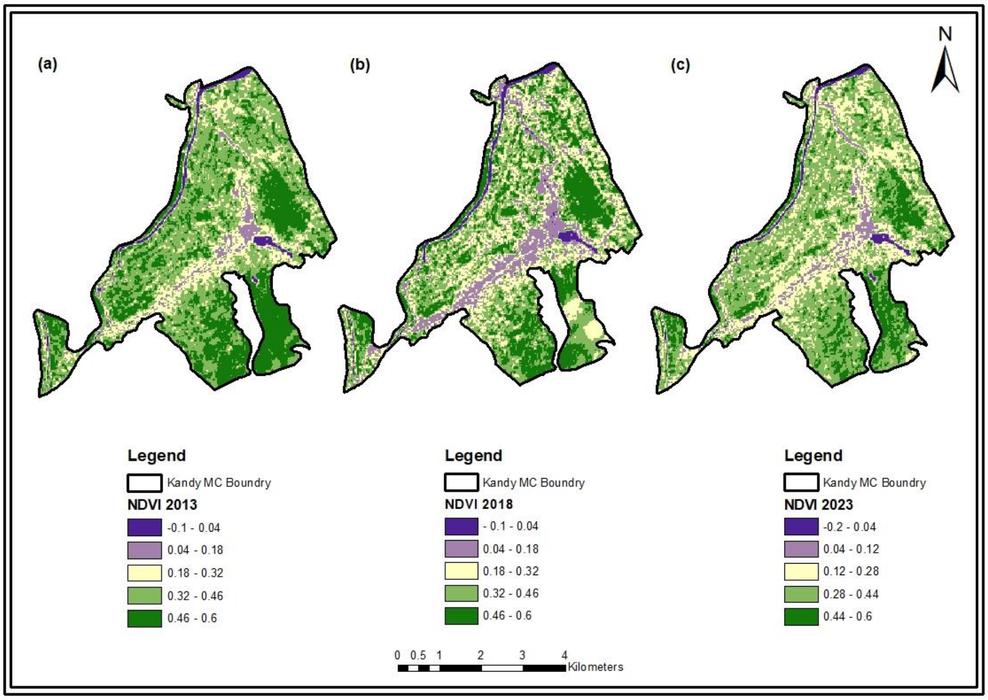

Figure 5 : Normalized Difference Vegetation Index (NDVI) maps of KMC
Source: 1:50,000 digital data and Google satellite data

### *3.3 NDWI in 2013, 2018 and 2023*

The analysis of NDWI variability across the time points of 2013, 2018, and 2023 reveals significant changes in water dynamics within the studied area (Figure 6). In 2013, the NDWI values spanned from -0.2 to 0.4, indicating a substantial capacity for water storage. Particularly noteworthy was the region extending towards the east and southeast, characterized by an elevated NDWI range between 0.28 and 0.4, signifying a surface well-equipped to store significant amounts of water.

Moving to 2018, the NDWI range contracted slightly, ranging from -0.2 to 0.3, with a mean value decreasing to 0.05. A notable observation is the diminished water storage capacity, especially towards the southeast, where a lower NDWI range of 0.0 to 0.3 suggests reduced potential for water retention compared to the preceding year, 2013.

By 2023, the NDWI values maintain a range between -0.2 and 0.3, with a consistent mean value of 0.05. Despite a historical dip in water storage capacity in the middle of the city during 2013 and 2018, the NDWI values for 2023 showcase an increase. Simultaneously, a decrease in NDWI in the range of 0.1 to 0.2 in the eastern and southeastern regions suggests a dynamic change in water dynamics, emphasizing the resilience and adaptability of the studied area over the years.

This geographically informed analysis underlines the evolving nature of water storage capacity in different zones of the region, shedding light on both historical trends and future projections based on NDWI variations.

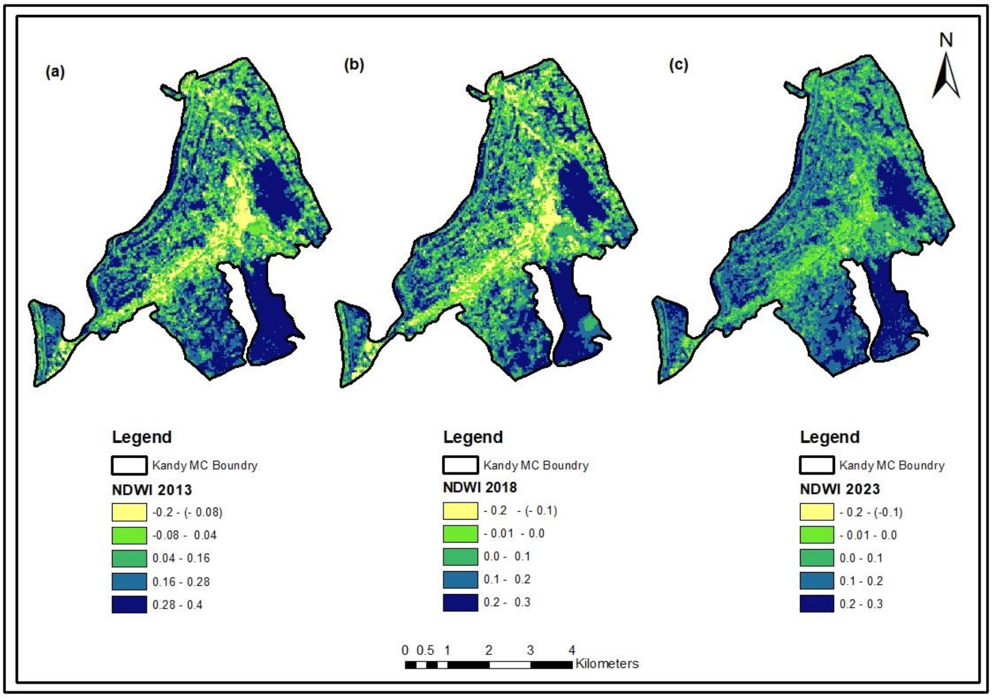

Figure 6: Normalized Difference Water Index (NDWI) maps of KMC
Source: 1:50000 digital data and Google satellite data

### *3.4 NDBI in 2013, 2018 and 2023*

The NDBI map (Figure 7) for the years 2013, 2018, and 2023 provides a comprehensive overview of the changing urban landscape. In 2013, the NDBI values span from -0.36 to 0.15, with a median of -0.105, indicating a diverse mix of built-up and non-built-up areas. The negative values likely correspond to natural features, while positive values suggest potential urban structures. Fast forward to 2018, where the NDBI values for built-up areas fall within the range of 0.05 to 0.15, with a mean NDBI (Normalized Difference Build - up

Index) value of 0.07. The built-up areas, characterized by an NDBI range of 0.9 - 0.2, show a notable increase compared to 2013, signaling urban expansion and development.

Moving to 2023, the NDBI values in built-up areas have further expanded, ranging from -0.33 to 0.24, with a margin of 0.045 compared to 2013. This growth is indicative of ongoing urbanization or changes in land use patterns. Notably, raised areas in the map exhibit discernible growth over the years, underlining the dynamic transformation of the landscape. The increase in NDBI values, especially in these elevated regions, suggests the proliferation of built-up structures and infrastructure, potentially driven by urban development initiatives or population growth.

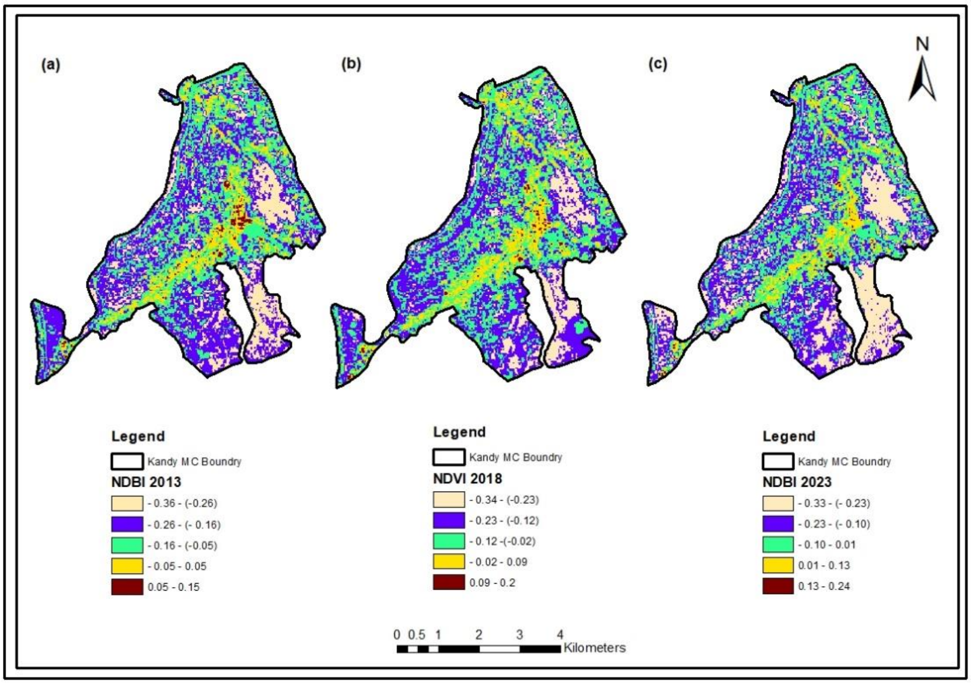

Figure 7 : Normalized Difference Built - up Index (NDBI) maps of KMC
Source: 1:50000 digital data and Google satellite data

### *3.5 Correlation in LST, NDVI, NDBI and NDWI*

In Figure 8, the correlation analysis between Land Surface Temperature (LST) and vegetation indices, namely Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), and Normalized Difference Water Index (NDWI), is presented for the years 2013, 2018, and 2023. Notably, a consistent negative correlation between LST and NDVI is observed across all three time points, indicating that as LST increases, the NDVI values tend to decrease. This negative relationship suggests a potential impact of temperature on vegetation health.

Furthermore, the correlation between LST and NDBI reveals a notably stronger relationship at the three specified time points. This suggests a more pronounced association between land surface temperature and built-up areas, emphasizing the influence of urbanization or impervious surfaces on temperature patterns.

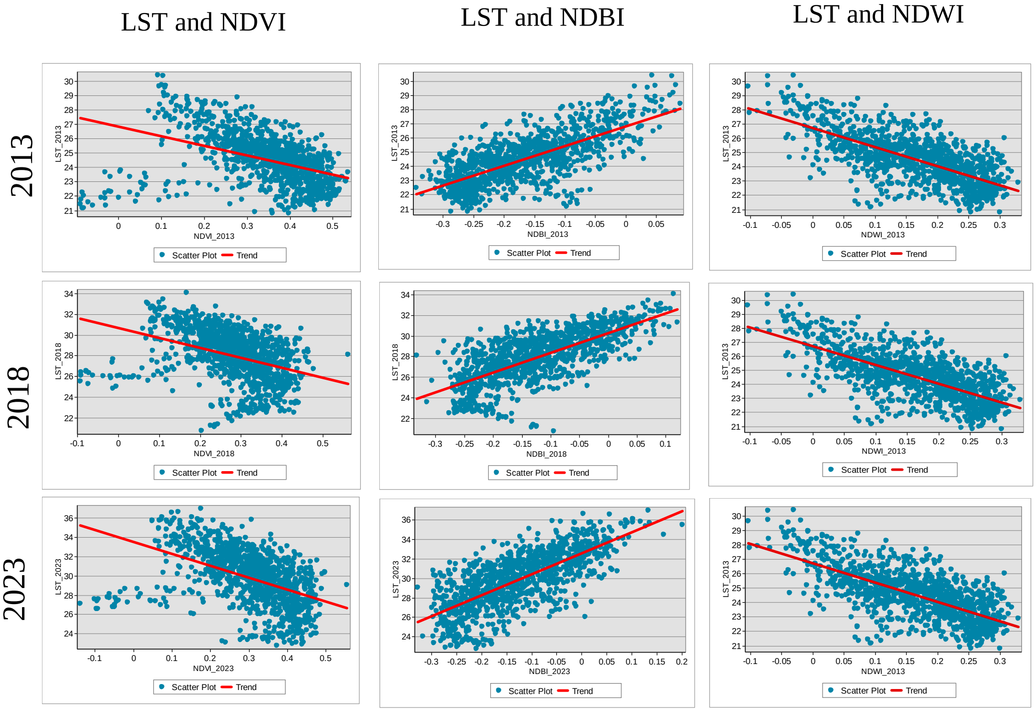

Figure 8: Scatter plots between NDVI, NDBI, NDWI and LST in 2013, 2018, and 2023
Source: LST, NDVI, NDBI and NDWI data

When analyzing LST in relation to NDWI, an interesting trend emerges. As LST values increase, there is a corresponding decrease in NDWI values. This negative correlation between LST and NDWI implies that higher land surface temperatures coincide with reduced water content in the observed areas. Geographically, this may indicate areas experiencing higher temperatures are also characterized by a decrease in water presence, which could be attributed to factors such as drought or land use changes. Overall, these findings provide valuable insights into the dynamic relationships between land surface temperature and different environmental indices over the specified time periods

### *3.6 Projected Temperature in 2033*

Looking ahead to the projected Land Surface Temperature (LST) values for the year 2033, the anticipated range spans from 32.88 degrees Celsius to 41.2 degrees Celsius. In comparison to the recorded minimum temperature of 23 degrees Celsius in 2023 February 15 (4.54.11GMT), there is a notable increase of 9.88 degrees Celsius in the projected minimum LST for 2033. This substantial rise suggests a significant shift towards warmer temperatures in the region over the ten-year period.

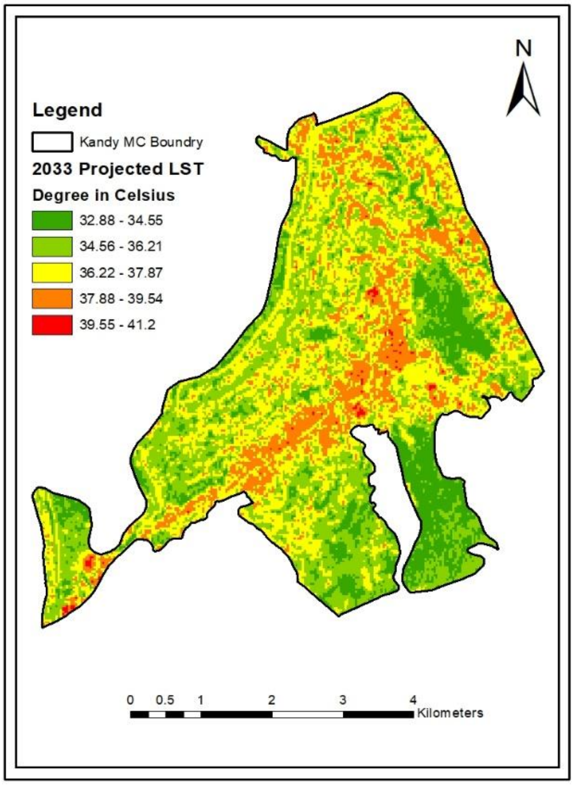

Figure 9: Land Surface Temperature (LST) map of KMC in 2033
Source: 1:50000 digital data and LST, NDVI, NDBI and NDWI data in 2023

Moreover, examining the maximum temperature values, which reach 41.2 degrees Celsius in 2033, there is a relative increase of 3.2 degrees Celsius compared to the maximum temperature recorded in 2023 February 15 (4.54.11GMT). This upward trend implies a persistent warming pattern over the decade, potentially influenced by various climatic factors and environmental changes.

From a geographic perspective, these temperature projections indicate a substantial alteration in the thermal conditions of the region. The notable increase in both minimum and maximum LST values highlights the potential for heightened temperatures, which could have implications for ecosystems, human activities, and overall environmental dynamics. Understanding and monitoring these temperature trends are crucial for informed decision-making and adaptation strategies in the face of evolving climatic conditions.

## 4. Discussion

### *4.1 Kandy Urbanization*

The city of Kandy, cradled within a panorama of luxuriant landscapes and embraced by approximately two-thirds of the majestic Mahaweli River, stands as a testament to natural beauty. Its allure is further heightened by key ecological treasures, including the Udawatta reserve, the verdant Wakarawatta forests, and essential water sources like Hali ela, Deniya ela, Meda ela, Hal oya and Piga oya, all of which collectively play a pivotal role in preserving the delicate ecological balance of the city (2019 – 2030 development plan for Kandy). However, this pristine equilibrium faces a formidable threat in the form of rapid urbanization.

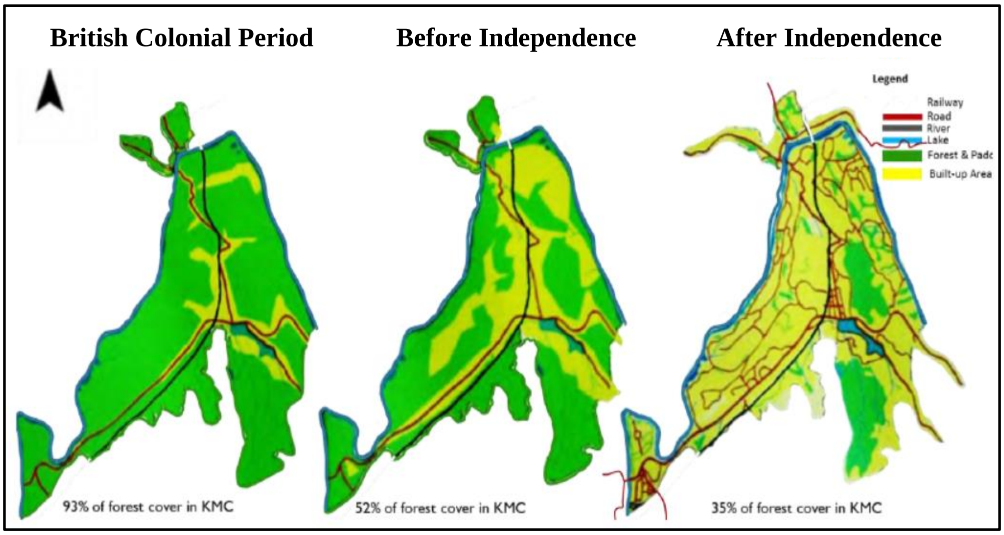
**British Colonial Period** **Before Independence** **After Independence**

Figure 10: Kandy vegetation covers
Source: Kandy city development studies, Department of Town and Country Planning, University of Moratuwa, 2014

Over the years, Kandy has witnessed a concerning depletion of its once-thriving vegetation cover. During the British colonial period, the city boasted an impressive 93% coverage, only to see it dwindle to 52% in the pre-independence era and further diminish to a mere 35% in the after-independence era (2019 – 2030 development plan for Kandy). This stark reduction in greenery serves as an ominous indicator of the challenges posed by the accelerating pace of urbanization.

Kandy, finds itself at the epicenter of intense urbanization for popular schools, healthcare facilities, places of worship, and major administrative centers. A comprehensive traffic study conducted in 2014 revealed that a staggering influx of nearly 325,000 individuals migrate to the city daily, accompanied by an armada of almost 56,000 vehicles. These figures starkly illuminate the magnitude of urbanization within the city limits and the ensuing strain on its infrastructure and resources.

Amidst this urban surge, Kandy grapples with a burgeoning concern – urban heat stress. The diminishing vegetation cover and the proliferation of impervious surfaces contribute to this ecological challenge by amplifying the reflection of solar radiation (Trusilova.,2009). As concrete landscapes replace greenery, surfaces that once absorbed sunlight are replaced with those that deflect it, resulting in elevated temperatures known as the urban heat island effect. This poses a multifaceted threat, impacting not only the city's environmental health but also the well-being of its residents.

### *4.2 Mitigating Urban Heat Island Effect in Kandy MC: Strategies and Implications*

In the heart of Sri Lanka, the city of Kandy stands as a testament to the harmonious coexistence of urban development and environmental preservation. The "Magen gasak mahanuwarata" (kandy.mc.gov.lk) initiative has taken root, becoming a symbol of community engagement in fostering a green and sustainable urban landscape. This program not only contributes to improving air quality, but it also sparks the imagination of a future where trees play a pivotal role in regulating the surface temperature of Kandy's urban expanse.

The lush greenery provided by the tree planting program serves as the lungs of the city, (Estoqeu et al,2017) absorbing pollutants and releasing oxygen, thereby enhancing air quality. As the city evolves, these green spaces become sanctuaries for both nature and residents, offering a breath of fresh air amidst the hustle and bustle of urban life.

Looking ahead, the visionary Kandy City Plan 2019-2030 outlines a roadmap for sustainable urban development. One key element in achieving this vision is the "Neela haritha parisaraya" project, a strategic endeavor aimed at restoring environmental balance (2019 – 2030 development plan for Kandy). This comprehensive plan recognizes the significance of both blue and green elements in urban planning – water bodies and vegetation. It emphasizes the need to integrate these components seamlessly into the cityscape to create a resilient and ecologically sound urban environment.

Towards 2030, the city of Kandy aspires to exercise precise control over its temperature profile. The desired temperature control, as outlined in the city plan, becomes a beacon guiding the city towards a more comfortable and sustainable future. This forward-thinking approach envisions a city where the urban heat island effect is mitigated through innovative and strategic interventions.

The "Neela haritha parisaraya" project emerges as a cornerstone of Kandy's temperature control strategy. By incorporating water bodies into the urban fabric, the project aims to counteract rising temperatures and create microclimates that provide relief from the scorching urban heat. Lakes, ponds, and green spaces act as natural coolants, fostering a more temperate urban environment that is not only pleasant for residents but also conducive to biodiversity.

Looking beyond the local context, the global discourse on urban heat islands has gained momentum. The collective goal is to reduce the adverse impacts of urban heat islands, promoting sustainability and resilience in the face of climate change.

This heightened attention to heat-related environmental and health issues has spurred the development of innovative heat island reduction strategies. Trees and vegetation stand out as nature's air conditioners, offering shade and evaporative cooling. Kandy's "Magen gasak mahanuwarata” initiative aligns with this global trend, showcasing the power of community-driven tree planting programs in combatting the urban heat island effect.

Green roofs and cool roofs are emerging as additional tools in the arsenal against rising urban temperatures. Green roofs (EPA.,2018), adorned with vegetation, provide insulation and reduce heat absorption, contributing to a more energy-efficient and cooler urban environment. Cool roofs, designed with reflective materials, bounce off solar radiation, preventing excessive heat absorption and lowering indoor temperatures.

In conclusion, Kandy's journey towards temperature control by 2030, as outlined in the city plan, is a beacon of inspiration for urban areas worldwide. By embracing the "A tree from me to Kandy" initiative the city not only tackles immediate challenges but also paves the way for a sustainable and resilient urban future. The global conversation on urban heat islands is evolving, and as cities increasingly recognize the importance of nature-based solutions, the trajectory towards cooler, greener, and healthier urban environments gains momentum.

## 5. Conclusion

Addressing the challenges of increasing urban sustainability and controlling urban heat in Kandy City is of utmost importance, particularly given the rapid urbanization taking place and the consequential environmental impacts. The ongoing development and expansion in Kandy underscore the immediate necessity to adopt effective strategies that not only promote urban growth but also prioritize sustainability and counteract the detrimental effects of rising temperatures. Urban sustainability, in this context, necessitates a comprehensive approach that seamlessly integrates ecological, social, and economic considerations, striking a delicate balance between developmental activities and the preservation of the environment. Concurrently, the issue of urban heat assumes critical significance, given the prevalent heat island effect in urban areas. This delves into a range of strategies aimed at bolstering urban sustainability and mitigating urban heat in Kandy City. From embracing green urban planning and promoting sustainable transportation to advocating climate-responsive architecture and fostering community engagement, these strategies collectively contribute to fortifying the city's resilience against climate change and nurturing a more habitable and sustainable urban environment for its residents.

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