URBAN HEAT ISLAND EVALUATION: A COMPREHENSIVE ANALYSIS OF STATE-OF-THE-ART APPROACHES IN DHAKA CITY

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ABSTRACT

High temperatures in the city centre than its surroundings are known as the Urban Heat Island (UHI) effect. Dhaka, the capital of Bangladesh and one of the world's largest megacities has experienced escalating social and environmental challenges due to rapid urbanization and infrastructure development, leading to prominent UHI issues. Furthermore, by not paying enough attention to the implementation of efficient heat mitigation methods in Dhaka City's present urban expansion, the effects of UHI might eventually become far more severe. Therefore, many governmental sectors and policymakers have been implementing operative solutions for cooling cities. Numerous research show that there is an increasing interest in recent years in the UHI phenomenon focusing on urban vitality, sustainability, and studies across the globe. This study depicts that it is required to develop sustainable solutions for mitigating the UHI effect and emphasizes the need for enhanced collaboration between scholarly research and the Architecture, Engineering, and Construction (AEC) industry. One of the major problems encountered to date is the change in the characteristics Land Use Land Cover (LULC) structure. Increasing the impervious surface cover has changed the thermal properties of urbanised areas. One of the most important problems facing urban planning today is UHI, which is largely due to the changing character of LULC. This paper employs thermal remote sensing to analyze the impact of Land Surface Temperature (LST), LULC and urbanization on Urban Heat Island (UHI) intensity in Dhaka city from 2000 to 2023. Over the 23 years, the Mean Annual LST for Dhaka city during the daytime exhibited notable increases, measuring 0.81ºC, 0.03ºC, 0.59ºC, and 0.62ºC for the years 2005, 2010, 2015, and 2020, respectively. Similarly, the Summer Mean LST values for Dhaka city during the daytime demonstrated a substantial upward trend over the same period, recording changes of 0.24ºC, 0.45ºC, 0.82ºC, 1.95 ºC, and 1.98ºC for the years 2005, 2010, 2015, 2020, and 2023, respectively. The study's projections reveal an alarming temperature increase, predicting a surge in Annual Mean LST by 3.2°C to 33.2°C and Summer Mean LST by 5.1°C to 35.6°C by 2050. This research's goal is to evaluate UHI through a comprehensive analysis, including explanatory diagrams, addressing Dhaka's limitations and challenges (thermally massive materials, low-albedo surfaces, complex urban morphology, waste heat, and limited vegetation) to alleviate it. In conclusion, the study highlights the urgent need for effective strategies to address the significant rise in land surface temperatures, especially during summers. It emphasizes the detrimental impact of replacing vegetation with urban land cover, contributing to increased UHI intensity. The research suggests that Dhaka's UHI problem stems from altered LULC structures and unplanned city planning. The study offers insights for future UHI research in Dhaka and practical recommendations for sustainable urban development, emphasizing public benefits.

Keywords: *Dhaka, Land surface temperature, Land use land cover, Remote sensing, Urban heat island.*

1. INTRODUCTION

In most large cities, the temperature at the centre of the city is found to be higher than its surroundings or the suburban area this phenomenon is called the Urban Heat Island (UHI) effect (Adinna et al. 2009). The rapid global population growth has driven swift urbanization and industrialization, bringing both positive and negative impacts on quality of life. Over the past five decades, urban population rates have escalated from 34% to 50%, with projections indicating a sustained upward trend (United Nations, 2014). The global urban population is anticipated to surpass five billion by 2030, leading to substantial impacts on land areas (Zhang et al., 2009). The rapid development of infrastructure in developing cities is converting natural ground surfaces into impermeable urban areas, replacing vegetation and soil with concrete structures. This transformation has profound implications for the urban environment, impacting ecological balance, sustainability, and the overall landscape (Nuruzzaman, 2015). The rise in population has significantly altered the land use/cover (LULC) characteristics, impacting key components like vegetation, topography, and water resources due to human activities. This transformation has modified the radiative and thermal properties of urban surfaces, primarily attributed to the extensive use of artificial impervious materials (Oke, 1995).

Land Surface Temperature (LST) is a sensitive indicator, reacting to changes in surface conditions and providing insights into energy distribution at the land-atmosphere interface. Researchers can analyse ground surface temperature variations and the effects of natural and human-induced changes by retrieving LST from remotely sensed thermal infrared data. (Mao and Dickinson, 2010). The transformation in land use, primarily driven by urban development, plays a crucial role in the UHI effect. Therefore, examining the spatial and temporal variations of UHI in tandem with urban development provides insights into identifying high-intensity areas and analysing cause-and-effect relationships at those locations (Zhang et al., 2009). UHI is considered one of the major problems in the 21st century posed to human beings as a result of urbanization and industrialization of human civilization (Rizwan et al., 2008b). The escalating pace of urbanization poses a persistent threat, with the UHI effect emerging as a prominent issue and contributor to climate change. Through statistical analyses of meteorological data, remote sensing, and physical modeling, research highlights the multifaceted impact of urbanization on global warming (Qiao et al., 2013b). In Turkey, rapid urbanization and industrialization have led to the emergence of UHI challenges, which are acknowledged at a national level. To address these issues, effective urban planning should take into account climate and topography. Introducing green elements in rehabilitation projects and implementing strategies such as green walls and corridors can mitigate rising temperatures and improve urban environments. (Dihkan et al., 2018).

With rapid urbanization, Dhaka, the capital of Bangladesh, is progressively falling short of sustaining outdoor life due to the UHI effects, which is one of the most documented phenomena of urban climate change, UHI intensity inside and around Dhaka varies from 2.5°C to 7.5°C, which leads to additional demand on the urban energy resources for cooling. While currently, 34.3% of Bangladesh's population lives in urban areas, it is projected to increase to 56% by 2050, which will eventually worsen the UHI phenomenon (Tasneem et al., 2022). Dhaka has a mere 0.12 acres of green and open space per one thousand people, falling significantly below the recommended 6.25 to 10.5 acres per thousand by the National Recreation and Park Association. Factors such as inadequate surface area, improper urban planning, air pollution, and more contribute to this growing issue, resulting in human discomfort, casualties, and adverse climate effects. The UHI effect is causing discomfort for urban dwellers, drawing global attention as the world undergoes urbanization and technological advances (Nuruzzaman, 2015). In developing countries like Bangladesh, conducting UHI studies becomes imperative for informed urban planning and development. Numerous references on the UHI effect underscore its substantial temporal variations, emphasizing the need for comprehensive investigations in such regions. This study employs satellite data to remotely analyse spatial and temporal changes in the UHI effect on Dhaka city. The research, conducted without in-situ measurements, aims to contribute to science-based sustainable urban planning. The investigation showcases variations in UHI characteristics across different directions in the study area, identifying hot and cold regions. Additionally, the study explores estimating UHI in the diverse built environment of Bangladesh's capital, emphasizing a critical examination of factors influencing outdoor thermal comfort in Dhaka city.

2. METHODOLOGY

The methodology employed in this study is designed to systematically investigate and analyse the multifaceted aspects of the UHI effect in Dhaka City. Within this context, we conducted a temporal analysis of Land Surface Temperature (LST) from 2000 to 2023 for Dhaka city. Simultaneously, a Land Use/Land Cover (LULC) map spanning the same period is generated. Graphical representations of temperature variations over time (2000-2023) will be crafted, followed by the calculation of the UHI index. The final step involves evaluating the current state of the UHI effect in Dhaka City. This methodological approach integrates cutting-edge geospatial analyses and quantitative assessments to provide a nuanced understanding of urban thermal dynamics and UHI trends over the past two decades.

2.1 Study Area

Dhaka city, the capital city of Bangladesh has been meticulously chosen as the focal point for this study, considering its rapid urbanization and emerging significance. In this study the term "Dhaka City" stands for "Dhaka Metropolitan Area (DMA)", which is located almost at the geographical centre of Bangladesh, the geographic coordinates are approximately Latitude: 23°42'37.44" N Longitude: 90°24'-

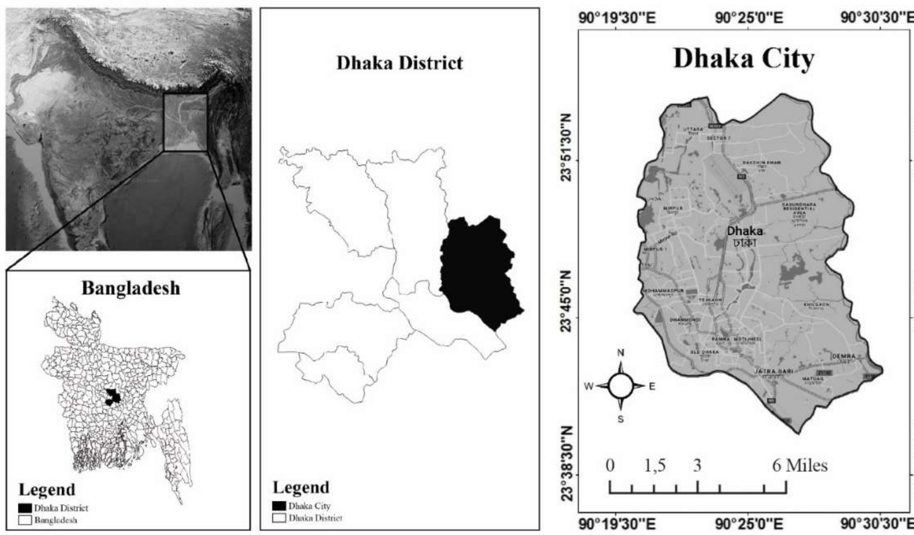


Figure 1: Geographic location of Bangladesh, Dhaka district and Dhaka city

26.78" E (Figure 1) (Ahmed et al, 2013 and Latitude. To. n.d.). It is the ninth-largest and seventh-most densely populated city in the world. With a staggering population exceeding 16 million residents, Dhaka city spans a total land area of approximately 304.16 km². This urban giant has witnessed an unparalleled population surge, with an increase of around 11 million people over the past two decades (Ahmed et al, 2011).

The unurbanized area adjacent to Dhaka City is presented here in Figure 2, which is considered by reviewing the previous study of Uddin et al. (2021).

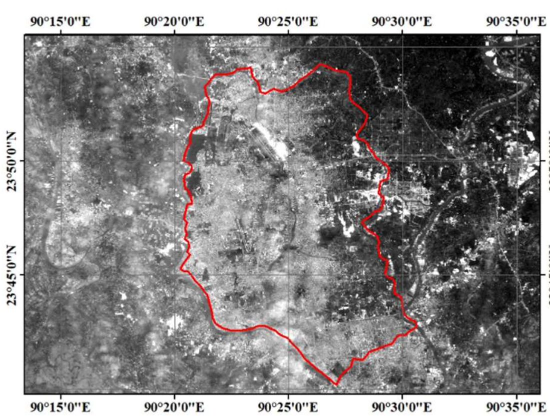


Figure 2: Considered area adjacent to Dhaka city

2.2 Temporal Analysis of Land Surface Temperature (LST)

The study analyses the UHI effects of Dhaka city leveraging the MOD11A1.061 Terra Land Surface Temperature and Emissivity Daily Global 1 km dataset spanning 2000 to 2023, involving a comprehensive exploration of daily LST variations. Seasonal analysis of LST and mean annual LST of Dhaka city has been done for 23 years (2000 to 2023) for seasonal analysis considering the winter and summer seasons in a year. According to the World Bank Climate Change Knowledge Portal, the warmest months coincide with the rainy season (April-September), while the winter season (December-February) is colder and drier. In this study, the summer season ranges from March to August, and the winter season from September to February. This temporal analysis aims to uncover the intricate thermal dynamics that have unfolded over the last three decades in Dhaka City.

Table 1: Specifications and pre-processing of the product

Product	**MOD11A1.061 Terra Land Surface Temperature and Emissivity Daily Global 1km**
Processing level	Level 2 (L2)
Spatial resolution	1 km
Temporal resolution	Daily
Scientific data set	Land Surface Temperature (LST) and emissivity
Reformat	HDF-EOS to Geo-TIFF
Reproject	Transform spatial data
Time period	February 24, 2000, to November 27, 2023
Grid size	1200 x 1200 km grid

2.3 Preparation of Land Use Land Cover

Through the creation of a detailed Land Use Land Cover (LULC) from 2000 to 2023 our study seeks to trace the evolution of land use patterns. This mapping exercise facilitates an understanding of how urban development and alterations in land cover may contribute to the observed Urban Heat Island (UHI) effect. One of the significant challenges in urban planning is the urban heat island (UHI) phenomenon, primarily driven by alterations in land use/cover (LULC) structures.

ArcGis 10.8 software tools were employed to perform the classification of the Landsat images. The land cover product has a spatial resolution of 30 m and is based on Landsat-4, Landsat-7, and Landsat-8 data, the product has 4 land cover classes. Data sources used in this study are shown in Table 2.

Table 2: Data and data sources

Data	**Path/Row**	**Resolution**	**Date**	**Source**
Landsat 4 (LULC 2000, TM)	133/04	30m	23/10/2000	USGS
Landsat-7 (LULC 2010,ETM+)	137/044	30m	10/03/2010	USGS
Landsat-8 (LULC 2023,OLI/TIRS)	141/045	30m	06/05/2023	USGS

2.3.1 Classification

The 4 land cover classes are bare soil, built-up area, vegetation, and water body, the classes were obtained from a literature review of a recent land cover classification study of the study area by Ahmed et al. (2013). Maximum Likelihood Supervised Classification (MLC) was chosen due to its ability to reduce misclassification errors compared to other methods like Parallelepiped and Minimum Distance. The details of the four classes are given here:

1) Bare Soil: Fallow land, earth, sand land in-fillings, construction sites, developed land, excavation sites, open spaces, bare earth, and other types of soil cover.
2) Built-Up Area: All forms of infrastructure from residential to commercial, mixed-use industrial areas, villages, urban settlements, road networks, sidewalks and man-made structures.
3) Vegetation: Trees, natural vegetation, a mix of woods, gardens, parks, playgrounds, and grassland. vegetation lands, farms, and crop fields.

4) Water Body: The river, permanent open waters, lakes and ponds, canals, permanent wetlands, low seasonal rainfall, Island areas, marshes, and swamps.

2.4 Graphical Representation of Temperature vs. Time:

To enhance the communicative aspect of our findings, this study constructs graphs illustrating temperature variations from 2000 to 2023. These visual representations provide a clear narrative of the temperature trends in Dhaka City over the studied period.

2.5 Evaluation of Current UHI State:

The study culminates in a meticulous evaluation of the current state of the UHI effect in Dhaka City. By synthesizing findings from spatial and temporal analyses, we aim to present a holistic understanding of the existing UHI dynamics in this rapidly evolving urban landscape. This methodology integrates geospatial analyses, advanced datasets, and quantitative assessments, providing a nuanced exploration of the UHI effect in Dhaka City over the past three decades.

3. RESEARCH FINDINGS AND RESULTS

The present study investigates the UHI effects of Dhaka city during daytime and nighttime. Our analysis includes a seasonal examination of LST and mean annual LST for Dhaka city spanning two decades (from 2000 to 2023). The study accounts for both winter and summer seasons each year to comprehensively assess the variations. This extended temporal analysis provides insights into the long-term thermal dynamics of urban areas, contributing to a deeper understanding of the UHI.

3.1 Land Use Land Cover

Land cover changes were characterized over the study period of 2010 to 2023. Figure 3 illustrates the LULC change map, emphasizing a surge in built-up areas between 2000 and 2023. The increase in built-up area is concentrated in the central and southwestern parts of Dhaka City. This shift is likely to intensify the UHI effect, contributing to increased energy consumption, heat-related illnesses, and reduced human comfort. Continued urban growth significantly diminishes vegetation and water bodies.

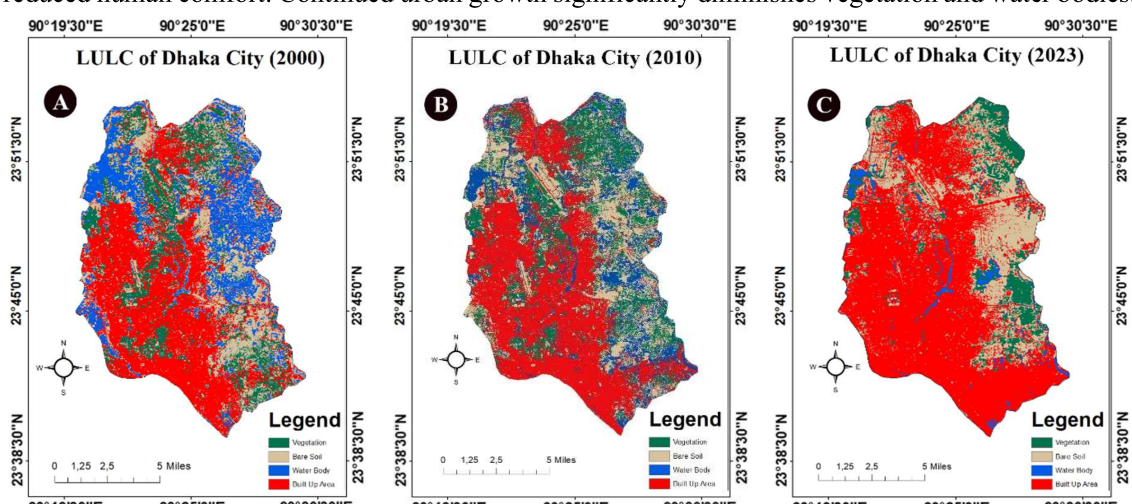


Figure 3: Land Use Land Cover change map for Dhaka for 2000 (A), 2010 (B) and 2023 (C)

The increase in built-up areas is accompanied by a decrease in the area covered by vegetation, water bodies, and bare soil. Over the period from 2000 to 2023, Dhaka City has undergone significant Land Use Land Cover (LULC) changes, reflecting a dynamic shift in the distribution of key land cover classes. The city witnessed a noteworthy decline in vegetation, shrinking from 49.1 km2 in 2000 to 41.54 km^2 in 2010 and further to 31.35 km^2 in 2023, signalling a loss of greenery. This represents a total change of 7.56 km^2 and a percentage decrease of 15.40% from 2000 to 2010, and an additional

10.19 km2 decrease with a percentage decrease of 24.53% from 2010 to 2023. Water bodies experienced a substantial reduction, decreasing from 56.9 km^2 in 2000 to 45.3 km^2 in 2010 and further to 8.9 km^2 in 2023. This indicates a significant decline in water features within the urban landscape, with a total change of 11.6 km^2 and a percentage decrease of 20.39% from 2000 to 2010, and an additional 36.4 km^2 decrease with a percentage decrease of 80.35% from 2010 to 2023. Bare soil showed a moderate decrease from 74.28 km^2 in 2000 to 68.72 km^2 in 2010 and 66.97 km^2 in 2023, suggesting alterations in soil exposure. In contrast, the built-up area exhibited a significant increase, expanding from 118.91 km^2 in 2000 to 141.61 km^2 in 2010 and further to 191.93 km^2 in 2023. This substantial increase in the built-up area reflects urban expansion and infrastructure development, with a total change of 22.7 km^2 and a percentage increase of 19.09% from 2000 to 2010, and an additional 50.32 km^2 increase with a percentage increase of 35.53% from 2010 to 2023.

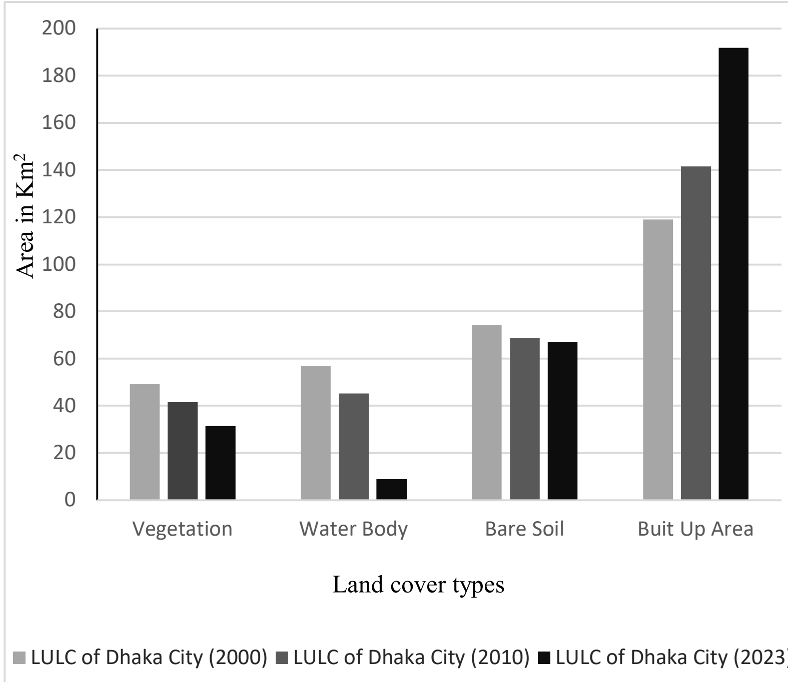


Figure 4: 2000 to 2023 land cover (km^2) proportion

The total area covered by all land cover classes throughout the study period remains relatively stable (297.17 km^2 to 299.19 km^2). The most significant increase in the built-up area occurred between 2000 and 2010. The decrease in vegetation cover is most pronounced in the peri-urban areas of Dhaka City. The increase in built-up area and the decrease in vegetation cover are likely to have a significant impact on the UHI effect in Dhaka City. Built-up areas absorb more heat than vegetation and water bodies. This is because built-up areas are made of materials with low albedo, such as concrete and asphalt. These materials absorb more sunlight and reflect less of it to space. As a result, built-up areas tend to be warmer than surrounding areas. The decrease in vegetation cover also contributes to the UHI effect. Vegetation helps to cool the air through evapotranspiration. Water vapour absorbs heat from the air, which has a cooling effect. The UHI effect can have several negative consequences, including increased energy consumption for cooling, increased air pollution, increased heat-related illnesses, and reduced human comfort.

3.2 Land Surface Temperature (LST)

The result of the LST analysis shows that there is high LST in highly built-up areas and low LST in non-built-up areas the land use land cover (LULC) map and land surface temperature (LST) image show a clear correlation between built-up area and high LST. This is because built-up areas are typically made of materials with low albedos, such as concrete and asphalt, which absorb more sunlight and reflect less of it to space. As a result, built-up areas tend to be warmer than surrounding areas. The LST image shows that the highest temperatures are concentrated in the central and southwestern parts of Dhaka City, which are also the most urbanized areas. This is consistent with the LULC map which shows that the area covers the majority of these areas.

The analysis of the Annual Mean Land Surface Temperature (LST) reveals distinct patterns in both daytime and nighttime temperatures, each playing a crucial role in understanding the dynamics of Urban Heat Islands (UHI). During the daytime, the period from 2000 to 2020 indicates a general warming trend, with intermittent fluctuations. The significant increase of 0.81°C from 2000 to 2005 suggests a warming pattern, followed by a stable period from 2005 to 2010, with a minimal increase of 0.03°C. Subsequently, from 2010 to 2015, there was a substantial rise of 0.59°C, indicating a return to a warming trend. The trend continues with a moderate increase of 0.62°C from 2015 to 2020. During the study time 2023 year has not ended yet so the annual data on change between 2020 to 2023 is not available yet. In contrast, nighttime temperatures exhibit a more intricate pattern. The substantial increase of 1.43°C from 2000 to 2005 indicates a pronounced warming during nighttime. However, the following period from 2005 to 2010 witnessed a remarkable decrease of -1.09°C, suggesting a significant cooling trend at night. The subsequent period (2010-2015) shows an analysis of the average changes in Summer Mean LST between the years 2000 and 2023 revealing intriguing patterns, particularly in both daytime and nighttime temperatures. For Summer Mean LST moderate increase of 0.58°C, followed by a decrease of -0.76°C from 2015 to 2020. Annual data on the change between 2020 to 2023 is not available. The analysis of the average changes in Summer Mean LST between the years 2000 and 2023 reveals intriguing patterns, particularly in both daytime and nighttime temperatures.

2000-01 2005-06 2010-11 2015-16 2020-21

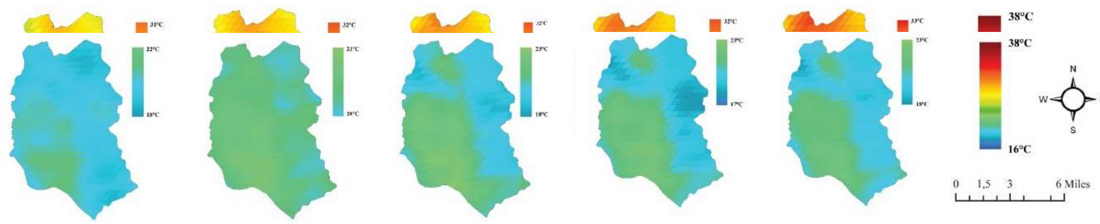
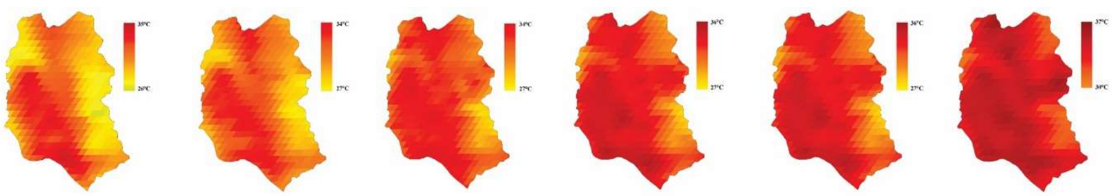


Figure 5: Annual Mean LST Day (ºC) for 23 years.

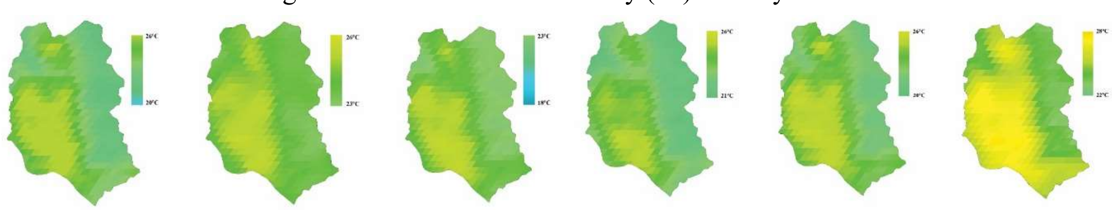
2000-01 2005-06 2010-11 2015-16 2020-21

Figure 6: Annual Mean LST Night (ºC) for 23 years.



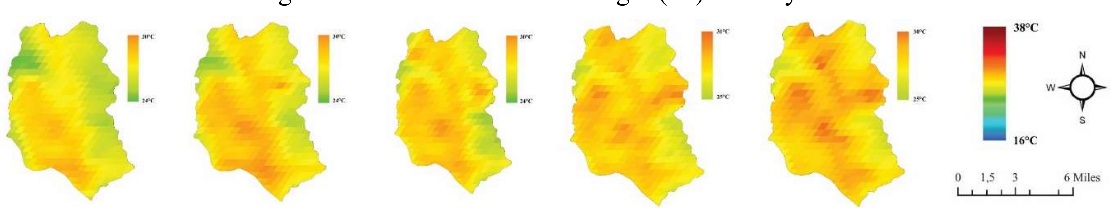
2000-01 2005-06 2010-11 2015-16 2020-21 2023

Figure 7: Summer Mean LST Day (ºC) for 23 years.



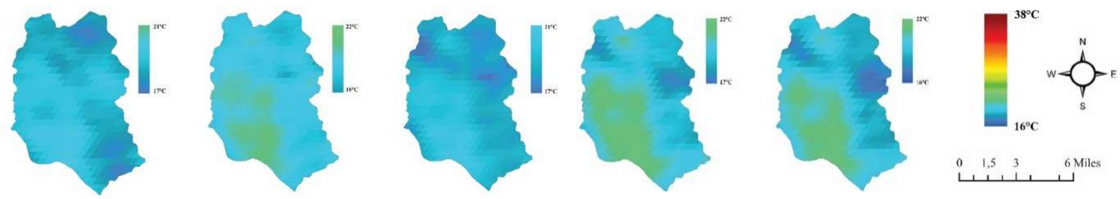
2000-01 2005-06 2010-11 2015-16 2020-21 2023

Figure 8: Summer Mean LST Night (ºC) for 23 years.



2000-01 2005-06 2010-11 2015-16 2020-21

Figure 9: Winter Mean LST Night (ºC) for 23 years.



2000-01 2005-06 2010-11 2015-16 2020-21

Figure 10: Winter Mean LST Night (ºC) for 23 years.

For Summer Mean LST Day, the period from 2000 to 2023 demonstrates a consistent warming trend. The average changes in degree (ºC) Celsius from one five-year interval to the next illustrate the intensification of daytime temperatures. From 2000 to 2005 and 2010 to 2015, there was a noteworthy increase of 0.24°C and 0.45° respectively, signalling a gradual warming. This trend accelerates significantly from 2010 to 2015 with an increase of 0.82°C and from 2015 to 2020, with an average change of 1.95°C, indicating a more rapid temperature rise. The continuation of this trend in the subsequent years (2020-2023) with a 1.98°C change reinforces the persistent warming pattern. The most substantial increase occurred in the latest interval of 2015 to 2020 and 2020 to 2023, with a striking 1.95°C and 1.98°C change respectively, underlining a notable surge in daytime temperatures.

Table 3: LST change for 23 years

Average change between years:	**2000 to 2005**	**2005 to 2010**	**2010 to 2015**	**2015 to 2020**	**2020 to 2023**
Annual Mean LST Day (ºC) change:	0.81	0.03	0.59	0.62	N/A
Annual Mean LST Night (ºC) change:	1.43	-1.09	0.58	-0.76	N/A
Summer Mean LST Day (ºC) change:	0.24	0.45	0.82	1.95	1.98
Summer Mean LST Night (ºC) change:	1.11	-0.33	-0.67	-0.11	0.06
Winter Mean LST Day (ºC) change:	0.40	0.08	0.44	0.12	N/A
Winter Mean LST Night (ºC) change:	1.09	-0.83	0.53	-0.26	N/A

Urban summer nights display fluctuating temperatures, characterized by significant warming and subsequent cooling, highlighting the dynamic nature of thermal conditions. Understanding these temperature dynamics is crucial for effective urban planning and climate adaptation strategies. From 2000 to 2005, there was a substantial increase in nighttime temperatures, with an average change of 1.11°C, indicating a pronounced warming trend during summer nights. However, the subsequent period from 2005 to 2010 experienced a contrasting trend, marked by a notable decrease with an average change of -0.33°C. This suggests a cooling phase during these years, showcasing the variability in nighttime temperatures. The cooling trend continued from 2010 to 2015, with a more significant average change of -0.67°C, indicating a substantial reduction in nighttime temperatures during this interval. The subsequent years from 2015 to 2020 depict a marginal cooling trend with an average change of -0.11°C, showing a further decline in nighttime temperatures. Interestingly, the pattern shifts in the most recent period from 2020 to 2023, where there is a slight warming trend with an average change of 0.06°C. This suggests a modest increase in nighttime temperatures during the latest years of analysis.

The analysis of Winter Mean LST for the period from 2000 to 2023 reveals notable trends in both daytime and nighttime conditions. Daytime temperatures exhibit a gradual warming trend, with a modest increase of 0.40°C from 2000 to 2005, a stable phase from 2005 to 2010 with a change of 0.08°C, and a significant warming trend from 2010 to 2015 with an average change of 0.44°C. The subsequent period from 2015 to 2020 shows a marginal increase of 0.12°C. Unfortunately, no data is available for 2020 to 2023. Nighttime temperatures, on the other hand, experienced a substantial warming trend from 2000 to 2005 (average change of 1.09°C), followed by a cooling phase from 2005 to 2010 (average change of -0.83°C). A moderate warming trend resumes from 2010 to 2015 (average change of 0.53°C), and a slight cooling trend is observed from 2015 to 2020 (average change of -0.26°C). Unfortunately, no data is available for 2020 to 2023.

3.3 Land Surface Temperature Trends Over Time

The trends in LST are analysed considering the Maximum LST, Minimum LST, Mean LST, Summer Mean LST, and Winter Mean LST over time (Every month of each year from 2000 to 2023).

3.3.1 Trend for Maximum Land Surface Temperature (Max. LST)

Figure 11 presents the Max. LST versus time, revealing a positive slope (0.0069) in the trend line equation (1). This suggests a gradual increase in maximum LST over the years, attributed to land use changes, and a decrease in vegetation and bare soil.

$$\text{Max. LST} = [0.0069\times\{\text{Time (month)}\}] + 31.77 \quad (1)$$

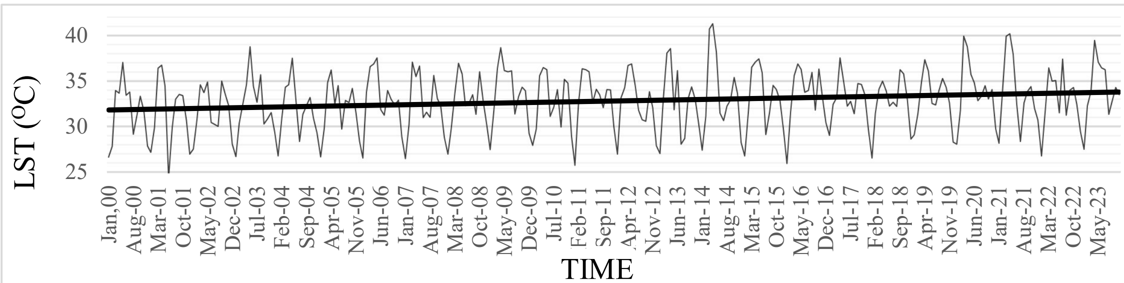


Figure 11: Annual Maximum LST (°C) vs Time for 23 years

3.3.2 Trend for Minimum Land Surface Temperature (Min. LST)

Figure 12 showcases the Min. LST versus time, with a positive slope (0.0136) in the trend line equation (2). This indicates a steady increase in minimum LST annually.

$$\text{Min. LST} = [0.0136\times\{\text{Time (month)}\}] + 22.036 \quad (2)$$

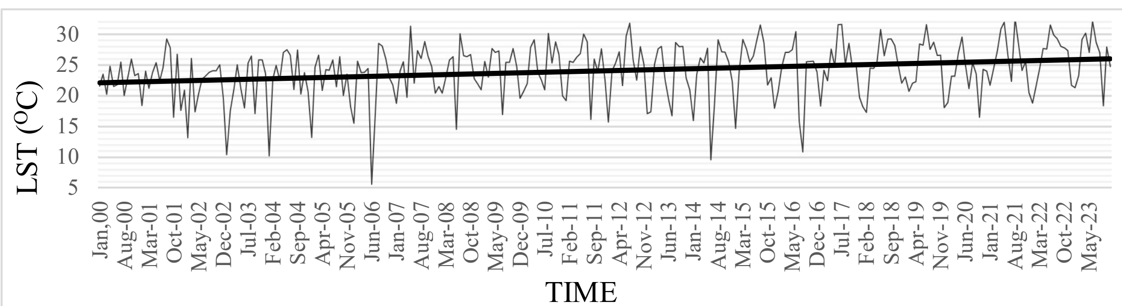


Figure 12: Annual Minimum LST (°C) vs Time for 23 years

3.3.3 Trend for Mean Land Surface Temperature (Mean LST)

Figure 13 depicts the Mean LST versus time, with a positive slope (0.0103) in the trend line equation (3). This suggests a consistent rise in mean LST over time, attributed to land use changes and vegetation.

$$\text{Mean LST} = [0.0103\times\{\text{Time (month)}\}] + 26.903 \quad (3)$$

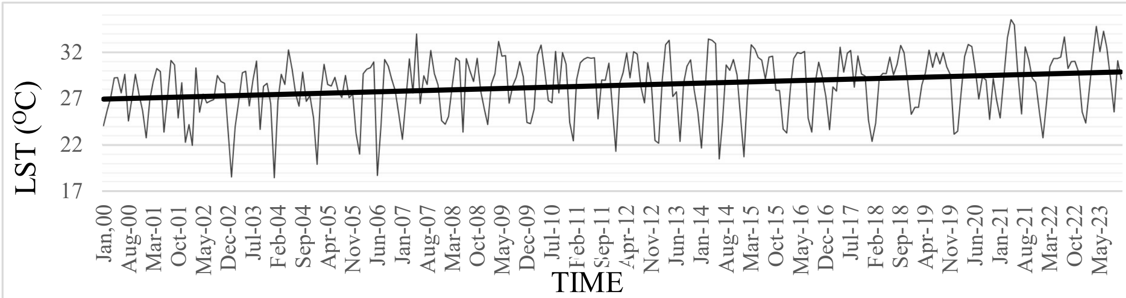


Figure 13: Annual Mean LST (°C) vs Time for 23 years

3.3.4 Trend for Summer Mean Land Surface Temperature (Summer LST)

Figure 14 illustrates the Summer Mean LST versus time, with a positive slope (0.0252) in the trend line equation (4). This indicates a steady increase in summer mean LST each year, driven by land use changes, a decline in vegetation and bare soil and also an increase in built-up regions.

$$\text{Summer LST} = [0.0252\times\{\text{Time (month)}\}] + 27.866 \quad (4)$$

3.3.5 Trend for Winter Mean Land Surface Temperature (Winter LST)

Figure 15 displays the Winter Mean LST versus time, with a positive slope (0.0143) in the trend line equation (5). This suggests a consistent increase in winter mean LST over time, associated with land use changes and reduced vegetation.

$$\text{Winter LST} = [0.0143\times\{\text{Time (month)}\}] + 26.02 \quad (5)$$

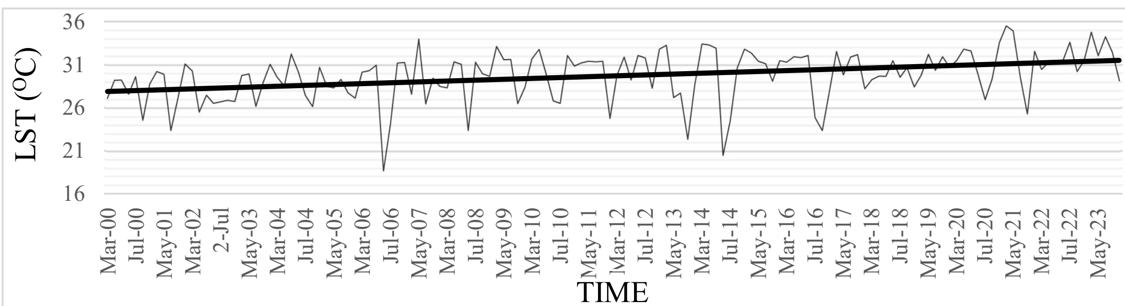


Figure 14: Summer Mean LST (°C) vs Time for 23 years

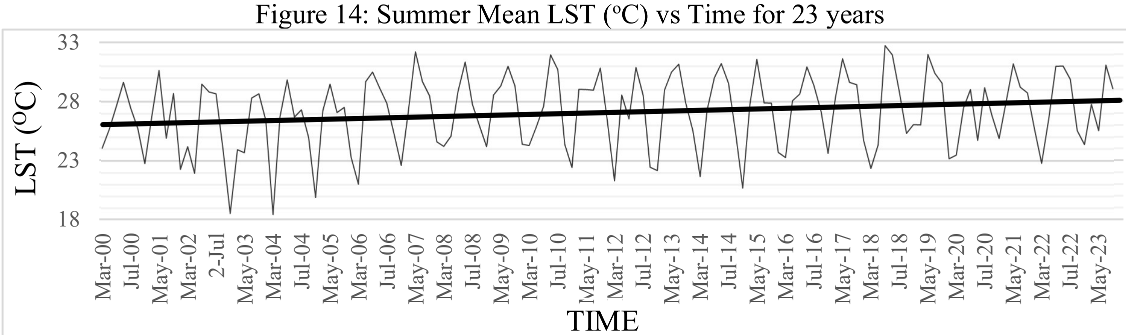


Figure 15: Winter Mean LST (°C) vs Time for 23 years

3.4 Future Trends in Mean Land Surface Temperature (LST)

Utilizing the established trend line and available data, we have forecasted the Mean LST for both annual and summer periods up to the year 2050. The prediction indicates a noteworthy increase in Mean LST.

3.4.1 Annual Mean LST Prediction

The prediction for Mean LST anticipates a surge to 33.2°C in 2050 from the baseline of 30°C in 2023. This indicates a significant increment of 3.2°C, reflecting the potential impact of ongoing trends in land use changes and vegetation reduction. Figure 16 shows the predicted Mean LST vs Time up to 2050.

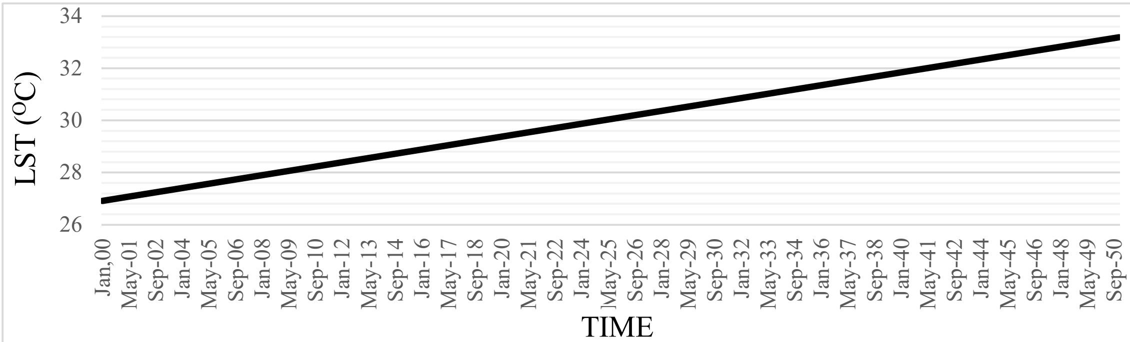


Figure 16: Predicted Mean LST (ºC) vs Time up to 2050

3.4.2 Summer Mean LST Prediction

Similarly, the prediction for Summer Mean LST anticipates a surge to 35.6°C in 2050 from the baseline of 30.5°C in 2023. This indicates a significant increment of 5.1°C, reflecting the potential impact of ongoing trends in land use changes and vegetation reduction. Such a significant rise underscores the urgency for comprehensive strategies to address and mitigate the effects of increasing land surface temperature, particularly during the summer months. Figure 17 shows the predicted Summer Mean LST over Time up to 2050.

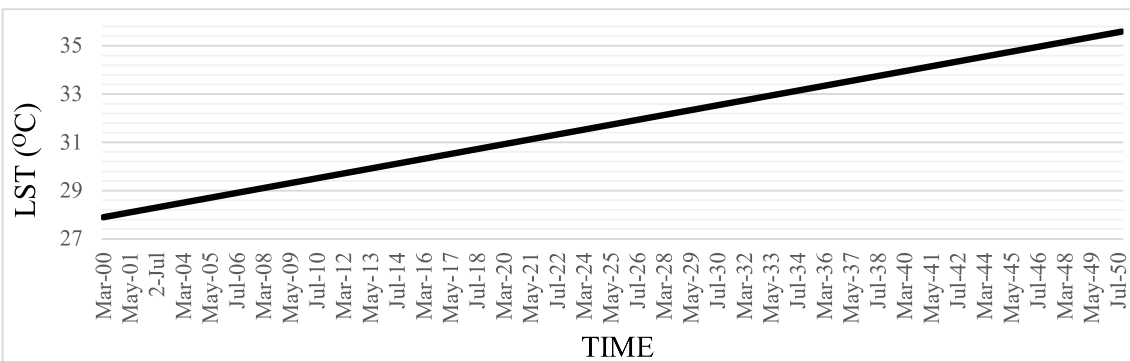


Figure 17: Predicted Summer Mean LST (ºC) vs Time up to 2050

3.5 Effects of Land Surface Temperature Change Adjacent to Dhaka City

To conclude the direct effect of urbanisation on the LST, this study compared urban Dhaka city LST with the study of Uddin et al. (2021), which was also done by considering the unurbanized portion adjacent to Dhaka city. Uddin et al. assessed the urban heat in Dhaka City by examining daytime and nighttime Land Surface Temperature (LST) for the years 2001, 2005, 2010, and 2017. Temperatures range from nearly 25°C to over 32°C for daytime LST and 17°C to more than 22°C for nighttime LST. The UHI is prominently observed in the northern and eastern regions of Dhaka city, correlating with rapid urban development. Nighttime temperatures show a lower difference (5°C) between Dhaka City and nearby regions. The temperature variation, ranging from 17°C to 22°C, is influenced by developed urban areas and water bodies, which exhibit higher convective characteristics. Urban heat-absorbing materials lead to increased nighttime temperatures in the city compared to its surroundings. Uddin et al.'s analysis indicates higher temperatures between latitude 90°20'00" to 90°25'00" and longitude 23°49'00" to 23°42'00", coinciding with the defined city region. The temperature peaks in the central region, emphasizing the impact of urbanization on temperature, are evident in the Urban Heat Island effect. Summer day and nighttime temperatures increase by 0.012°C and 0.04°C per year, respectively. Winter day and nighttime temperatures show increases of 0.047°C and 0.01°C per year. This comprehensive analysis provides valuable insights into the temporal and spatial dynamics of UHI effects in Dhaka City. It also cleared the concept that the effect of urbanisation has largely contributed to the LST increase in the city core where the vegetation and the water body have decreased over time and the temperature has increased.

4. CONCLUSIONS

In conclusion, the study on the Urban Heat Island (UHI) effects in Dhaka City, Bangladesh, underscores the urgency for sustainable urban planning and mitigation strategies. The analysis of LST in Dhaka reveals concerning trends, emphasizing the urgent need for measures against UHI. The correlation between high LST and built-up areas, seen in the Land Use/Land Cover (LULC) map, underscores the impact of urbanization on temperatures. Daytime temperatures show a warming trend with fluctuations, while nighttime temperatures exhibit intricate patterns of warming and cooling. The examination of annual, summer, and winter mean LST highlights temperature sensitivity to land use changes. Trends in Maximum LST, Minimum LST, and Mean LST over time indicate consistent temperature increases. Predictions foresee a substantial rise in Mean LST by 2050, reaching 33.2°C annually and 35.6°C in summer. Urban heat-absorbing materials lead to increased day and nighttime temperatures in the city's urbanised area compared to its surrounding unurbanized portion. Urgent actions, such as emphasizing green spaces and eco-friendly materials, are vital for Dhaka's sustainable development and residents' well-being amid rising temperatures. Aligning urban development with climate-conscious strategies is crucial for building a resilient and sustainable city. Bangladesh has a rich variety of flora that needs to be explored and a green database needs to be formed by Government initiative that can act as a guideline for planners. The paper strongly recommends an immediate increase in the percentage of green spaces, coupled with strategic measures to monitor and mitigate UHI effects in Dhaka. The study's results suggest that the altered Land Use/Land Cover (LULC) structure and anthropogenic pressures on city planning geometries contributing factors to the UHI issue in Dhaka.

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