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Urbanization and Land Surface Temperature Dynamics in Tangail Pourashava: A Spatio-temporal Study

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ABSTRACT

This study investigated two decades of urbanization and Land Surface Temperature (LST) dynamics in Tangail Pourashava from 2003 to 2023. With the help of Landsat data and GIS tools, this study evaluates changes in LULC, checks temperature variations, and explores how they are linked. It was noted that built-up areas expanded, approximately 58%, accompanied by a marked decline in agricultural (-33%) and vegetated land (-20%). Correspondingly, the LST increased from 29°C in 2003 to 33°C in 2023, with the LST closely linked to urban built-up areas and bare land and negatively correlated to vegetated, agricultural, and water areas. Urban expansion was most pronounced towards the northeast and southwest, caused by roads, real estate markets, and other factors. It has been confirmed that there is a growing UHI effect, intensifying environment and public-health vulnerabilities. The results highlight the importance of planning, building vegetation land, and enforcing zoning rules in expanding secondary cities to combat climate change. Together, these approaches provide a reliable method for assessing urban environmental changes and preparing these regions to tackle climate change.

1. Introduction

The growth of cities in recent times has dramatically changed the world's landscapes, communities, environmental settings, and economies. Now, about 56% of all people live in urban areas, but as predicted by the United Nations, this will reach 68% by 2050 (UN-Habitat, 2022). Rapidly growing cities are reshaping city districts and adding new environmental issues linked to climate change, environmental degradation, and risks to people's health. With both sides of cities becoming more crowded, academics and policymakers have raised serious concerns about rising temperatures, scarcity of resources, air pollution, and how energy is used (Das et al., 2024; Marolla, 2024). Lately, research into how urbanization raises average Land Surface Temperatures (LST) has become a significant area of concern.

Urbanization can have multiple meanings in various fields, including sociology, geography, economics, and demography. While some definitions define regions by a settlement's population, others also take economic and social factors into consideration (Dijkstra et al., 2021). A major driving factor of urbanization is the need for better access to social and economic benefits, including superior education, healthcare, housing, career opportunities, and self-realization (Byulegenova & Turemuratov, 2023). This urbanization leads to the removal of existing vegetation and the construction of infrastructure, resulting in habitat loss, fragmentation, and isolation. This significantly impacts the environment and ecosystem processes (Ruas et al., 2024). Urbanization and global warming significantly increase the Land surface temperature in a particular urban area, which can lead to changes in local climates and make metropolitan areas obsolete (Halefom

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et al., 2024). Land surface temperature is defined as the thermodynamic temperature of a thin layer at the interface between the soil, vegetation, or other surface components and the atmosphere (Li et al., 2023). The expansion of impervious surfaces like buildings, roads, and other urban facilities, the reduction of vegetation and water bodies, high building density, and other humans' daily activities contribute to LST increase (Wang et al., 2023). Another leading example of urban-caused heat stress is the Urban Heat Island (UHI) effect, where cities have much higher temperatures than rural areas because of sealed surfaces, heat produced by people, and a lack of vegetation (Liu & Niyogi, 2019).

Research consistently shows a direct relationship between urbanization and LST. As urban areas expand, LST tends to increase in parallel. For example, in Jeju Island, an increase in urban land from 8.69% in 2002 to 20.81% in 2021 corresponded with a rise in surface temperature from 19.40°C to 24.16°C. This similar pattern was also found in other cities globally, including Guangzhou, Seoul, Beijing, Kolkata, Lahore, and Rajshahi (Moazzam et al., 2022; He et al., 2024). They found LST significantly increased from 28.1°C to 30.7°C from 2013 to 2022, indicating an intensification of the UHI effects due to the rapid growth of urbanization.

Since there are many different and changing aspects of urban expansion, it is necessary to use solid and data-driven tools for studying LST. Examining urban growth and changing temperatures in an area over time now relies on using GIS, remote sensing, and thermal imaging (Wu et al., 2021; Gupta et al., 2023; Liu et al., 2023). They make it possible to monitor changes in land use and land cover, vegetation losses, growth of paved areas, and their impact on the surface temperature. In addition, data from Landsat and MODIS remote sensing can show the development of environmental changes in different cities over time (Gao et al., 2024). Regardless of all these new technologies, most research highlights megacities and metropolitan centers, while the secondary urban areas are seldom included.

Many researchers have looked into the urban heat island effect in South Asia and found that the fast development of cities, less green space, and increasing infrastructure cause urban temperatures to rise (Dewan et al., 2021). Although Narayanganj, Khulna, and Tangail are important for population growth, economic changes, and the use of land, they are not given much attention in urban climate studies (Fattah et al., 2021; Rashid et al., 2022). These secondary cities have special ways of being managed, their infrastructure, and how land is looked after. The mid-sized and fast-growing Tangail Pourasha**va** in central Bangladesh, 98 kilometers from Dhaka, is a good example of a developing urban city. Over the past two decades, Tangail's population has increased substantially, leading to urban expansion that has encroached upon agricultural fields and converted wetland areas into built-up land (Sarker et al., 2015; Rahman & Mamun., 2025). As a result, local climate conditions have suffered, with increased temperatures and reduced air quality.

While numerous national-level studies have examined the overall increase in cities and warmer temperatures, few have analyzed these issues in Tangail (Sarker, 2020; Dewan et al., 2021). The existing works do not often mix LULC and LST datasets for more extended periods, which makes it hard to spot changes that slowly affect surface temperatures. Such a gap limits the development of strong, adaptive climate resilience tactics for different communities. Considering that flooding, erosion, and agricultural threats are regular issues in Tangail, examining its land use transformation and surface temperature changes extensively for modern planning and curbing disasters (Mamun et al., 2018; Arias, 2021; Rahman et al., 2022).

Given the scarcity of prior scholarly work, several dimensions of this issue remain insufficiently examined. Accordingly, the present study analyzes the long-term dynamics of urban expansion and associated land surface temperature variations in Tangail Pourashava across the period 2003 to 2023 (Sharker et al., 2025). The study uses satellite images from different times, weather data, and GIS tools to identify how cities are developing, how surface temperatures vary, and the link between land use and higher temperatures. These research questions guide the research project: How has the pattern of urbanization in Tangail Pourashava shifted from 2003 to 2023, in terms of space and periods? How has the variation in land surface temperatures looked over the last ten years? Which aspects most strongly influence the link between urban growth and higher LST, and how do they work together? To deal with these questions, the study follows three main objectives. The first goal is to identify land use changes over time and space using LULC maps produced from Landsat images. Key locations of urban change are listed by checking how much built-up space is increasing and how much vegetation and farmland are being lost. Secondly, it studies changes in land surface temperature over different times using thermal band information and meteorological data recorded from the ground to find any temperature trends or anomalies. Third, the research examines the connections between changes in land cover and temperature using spatial correlation and regression to see how surfaces that lack vegetation and changes caused by people play a part in temperature variations.

There are many reasons why the study was carried out in Tangail Pourashava. This city, first, acts as a common type of secondary urban center for countries going through the change from farms to industries. Furthermore, cities' rapid and unplanned expansion will most likely increase local climate risks. Further, environmental and economic changes allow us to look at and relate wider urban-environmental patterns between different regions. As a result, the research adds to what is known about urban climate change in the Global South and to international publications on this subject (Sarker et al., 2015).

This research will add valuable information to the existing studies about cities' thermal climates and innovative land management. Such data helps create plans to deal with the increased heat risks resulting from changes in land use and build more climate-resistant urban areas. Additionally, the research helps local governments, urban planners, and policymakers to balance economic growth with an effort to protect the environment. It points out that building green infrastructure, controlling how cities expand, and planning for climate zones are all ways to address the heat problem in cities. This research helps fill a key gap in urban climate studies by looking at a mid-sized city in Bangladesh that has not been well studied so far, and using integrated methods considering space and time. Studying the link between urbanization and land surface temperature contributes to understanding how secondary cities play a role in changing the environment and are affected by these changes. The study points out that geospatial technologies and remote sensing are now essential for planning for urban sustainability and coping with climate change as more people move to cities.

2. Research Methodology

2.1 Study area

Tangail Pourashava is an important urban area in the central part of Bangladesh, belonging to the Tangail District. The town's location, approximately 98 kilometers northwest of Dhaka, makes it a leading center for regional trading and the movement of goods. The population growth and fast development of Tangail Pourashava mean that it has seen many LULC changes, such as turning much agricultural land into new houses and shops (Sarker et al., 2015; Mamun et al., 2018).

Tangail Pourashava is a suitable spot for research in Bangladesh, due to its rapid urbanization, which started to exhibit UHI implications. Because of its primarily tropical climate and distinct wet and dry seasons, Tangail Pourashava is highly vulnerable to the effects of climate change, including extreme heatwaves (Sarker et al., 2015; Alam et al., 2016). The town's poor infrastructure plan has resulted in less vegetation and more solid surface, water flow blockage, resulting in increased Land surface temperature and UHI effects.

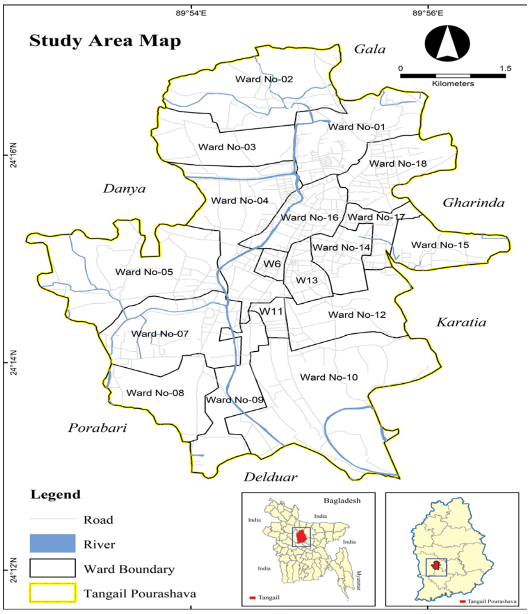

Figure 1. Tangail Pourashava as a Study Area.

Considering these circumstances, Tangail Pourashava is an important case to study to understand how urbanization and temperature play a role in climate change. With the findings of this research, there will be a pathway to understand the temperature patterns in the town and its region and see how this is linked to urban development in similar mid-sized cities in Bangladesh and developing countries (Zhang et al., 2017).

2.2 Data collection

This research used images from Landsat 9 OLI-TIRS and Landsat 7 ETM+ from 2003, 2013, and 2023 to perform visual analysis and identify land use types. Both Landsat 9 and 7 provide images with a spatial resolution of 30 m (Table 1).

Journals and magazines have played a role in pressing out different conceptual ideas through their articles. This study uses secondary satellite data as input. The USGS website (Table 1) provides much information about the Landsat images involved in this work. The Landsat image used for this study is from Path 137 and row 43 and shows the entire area. The images gathered from satellites are projected in Universal Transverse Mercator (UTM), Zone 45N, using World Geodetic System 1984 (WGS 84) as the datum (STAMBOLIYSKA, 2014; Li et al., 2017).

Table 1. Information about Satellite Imagery

Year	Data Acquired	SPACECRAFT	Sensor	Image Quality	Cloud Cover	Pixel size
2003	03/24/2003	Landsat 7	ETM+	9	1	30
2013	01/21/2013	Landsat 7	ETM+	9	1	30
2023	02/27/2023	Landsat 9	OLI_TIRS	9	1	30

2.3 Data processing

2.3.1 Images classification

Researchers used ERDAS Imagine 15 software to supervise the classification. Here are the steps involved in this method (Chepkochei, 2011; Long & Srihann, 2004). However, downloaded images were stacked one on top of the other, following the typical band combination format. The images were tied to a map with the help of the georeferenced files of Tangail City Pourashava. It is said that 100 reference points are chosen for creating the signature file, and 20 reference points are applied for each class in the satellite image used for classification, as there are five classes: urban, agricultural land, waterbodies, vegetation, and bare land (Bakr, 2017; Li et al., 2017). Google Earth was paired with ERDAS Imagine 15 before taking the points to ensure accuracy in choosing the references.

It uses spectral distance to measure the similarity between the pixels. In the Table 2, waterbodies, vegetation land, land used for farming, and the main parts of cities are easily noticed because they reflect light differently. In the case of beaches and dunes, farmland, and the rural-urban interface, making a clear separation between similar spectral values proved more difficult because the class pairs were less separated. Classification with human support was carried out using these signature files and a maximum likelihood algorithm (Kim & Lim, 2009; Glinsky et al. 2024).

Table 2. Land use/Land cover (LULC) classification scheme

Class Name	Description
Urban Area	All infrastructures include residential, commercial, mixed-use, industrial areas, road networks, pavements, and man-made structures.
Waterbody	River, lakes, ponds, wetlands, low-lying areas, marshy land, and Swamps.
Agricultural Land	Cropland and Pasture.
Vegetation	Trees, natural vegetation, mixed forest, grassland, vegetated lands.
Bare Land	Fallow land, earth, and sand land infillings, bare land.

Source: Adapted from (Cai et al., 2019; Nedd et al. 2021)

2.3.2 Assessing classification accuracy

The classified land cover maps were then validated using ground truth data from various sources. One hundred sample points were randomly selected from each year's land use/cover map. With this information, the accuracy of the maps generated was analyzed using the ERDAS Imagine 2015 software. The satellite image was used to evaluate the accuracy of the land use/cover maps. Thus, every year's accuracy was evaluated using data from 100 reference points (20 per class across five LULC categories). Overall, the accuracy of each land cover data was evaluated based on criteria such as overall accuracy, producers'/users' accuracy, and kappa coefficient (found in Table 3).

Table 3. Summary of classification accuracies (%) for 2003, 2013, and 2023

Year	Overall Accuracy (%)	Kappa Coefficient
2003	**89**	**0.864**
2013	**91**	**0.885**
2023	**92**	**0.90**

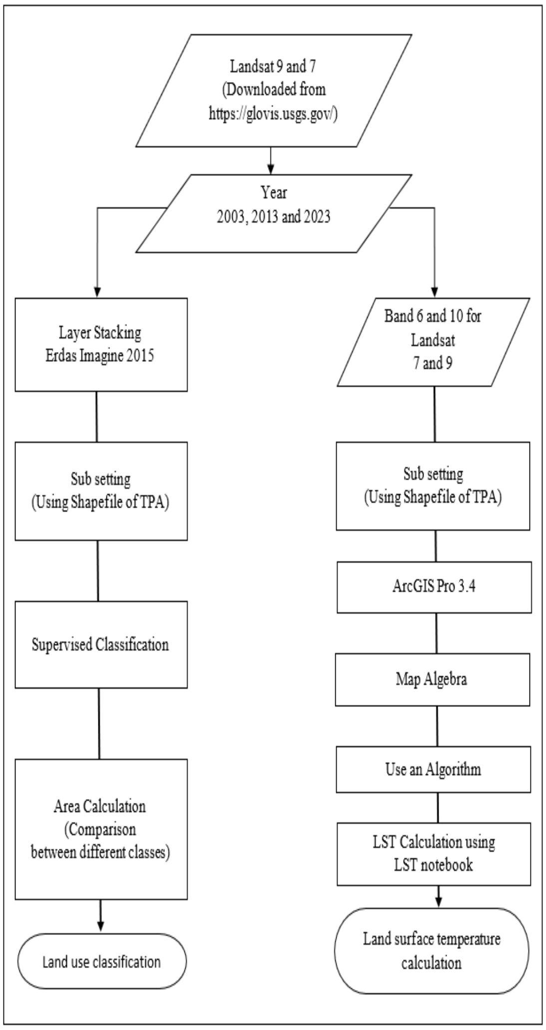

Figure 2. Methodological Framework of the Study.

2.3.3 Calculating Land Surface Temperature (LST)

2.3.3.1 Conversion to Radiance (Landsat 9)

The approach to determine temperature when working with the Landsat 9 satellite is by analyzing band 10 and converting it to spectral radiance using the scale factors in the metadata:

$$L\lambda = ML \times Qcal + AL$$

Where,

$L\lambda$ = Spectral radiance.

ML = Radiance multiplicative scaling factor for the band (RADIANCE_MULT_BAND_n from the metadata)

AL = Radiance additive scaling factor for the band (RADIANCE_ADD_BAND_n from the metadata)

Qcal = Level 1-pixel value in DN

2.3.3.2 Conversion to Radiance

The same two-step technique was applied to derive brightness temperatures from Landsat 7 and 9 images. To begin with, the DN values of band six were converted to radiance using this equation:

$$\left[\frac{Lmax_{\lambda} - Lmin_{\lambda}}{Qcalmax - Qcal\ Min}\right] Qcal - Qcalmin + Lmin_{\lambda}$$

Where,

Qcal= The quantized calibrated pixel value in Digital Number (DN)

Qcalmin= The minimum quantized calibrated pixel value (DN=1)

Qcalmax=The maximum quantized calibrated pixel value (DN=255) corresponding to LMAXλ

Lminλ = The spectral radiance that is scaled to Qcal min.

Lmaxλ= The spectral radiance that is scaled to Qcal max.

2.3.3.3 Conversion of Radiance to Atmosphere Brightness Temperature

LST has been calculated based on the emissivity adjustments and the radiance measurement from the satellite image's thermal band. The required information for computing land surface temperature is in the header file (metadata) accompanying the satellite images. The DN values of the thermal bands from the images were first transformed into radiance values (Lλ), which in turn were translated into At-Satellite Brightness Temperature. The data from the thermal band can be transformed from spectral radiance to brightness temperature using the information obtained from the metadata file using the following equation.

$$\frac{K2}{\left({}^{K1}/_{L\lambda}+1\right)-273.15}$$

Where,

T = At-Satellite Brightness Temperature (K) in the Kelvin scale

Lλ = TOA spectral radiance

K1 and K2 = Band-specific thermal conversion constants from the metadata.

The satellite temperature obtained on the Kelvin scale was then converted to degrees Celsius. Landsat 7 used band six to determine the land surface temperature, while Landsat 9 OLI uses thermal bands (bands 10 and 11). The final output was the average of the values obtained from both bands.

2.3.4 LULC change detection analysis

LULC change detection analysis for Tangail Pourashava between 2003 and 2023 was done using ArcGIS and a straightforward step-by-step process. Initially, satellite images taken in 2003 and 2023 were gathered, and both datasets were checked and corrected for any geometric and radiometric errors. The images were categorized through a supervised method, Maximum Likelihood Classification (MLC), using well-represented LULC types such as built-up regions, vegetation, water, and bare land. Every majority-classified image was checked for accuracy by making confusion matrices and computing Kappa coefficients with the help of ground truth and other high-quality resources. After the land cover forecast was successful for both years, a measure was used where the areas classified in 2003 and 2023 were compared to detect changes from one land cover class to another. The "Change Detection Matrix" tool was employed in ArcGIS Pro to count transitions, making it possible to observe and visualize regions that saw significant changes in their type of land. At the end, a range of change maps and statistics were prepared to highlight the mainland cover transitions, such as increasing development in areas previously occupied by agriculture or vegetation, offering key information on urbanization trends and their environmental influence.

2.4 Estimation of Gradient Direction (GD)

This is a fine-scale way to analyze land use and land cover (LULC) over time and space (Kafy et al., 2021; Cao et al., 2024). In the initial step, concentric rings were regularly drawn outward from the city's center, so the outermost ring covered every type of land use and land cover in the region. Next, 16 rays emanated from the city center, each evenly placed 22.50 degree apart. These radial lines met the concentric circles, which made different zones. The zones were then examined in terms of their LULC to identify and interpret any changes or differences in the types of landscape and their development.

3. Result

3.1 Spatiotemporal Changes of Land use and Land cover (LULC)

3.1.1 Land Transformation and Urban Expansion in Tangail Pourashava: A Two-Decade LULC Analysis

Figure 3 shows that urban development has been the leading cause of the noticeable transformation in Tangail Pourashava's landscape over the past two decades. In 2003, the region showed various types of land use, including a significant amount of farmland, forests, and smaller urban areas. All over the Pourashava, vegetation land and farmlands are found that help balance the environment. Urban areas in red are generally found in small bits and spreads, reflecting land management that balances housing needs with protecting nature.

By 2013, a noticeable shift occurred. Urban areas grew a lot, most notably in the central, northeastern, and western areas of the pourashava. As a result, the flat open spaces and farming fields were carved up, making them scattered in size and connectedness. Because of the pressure of development, cities have gradually expanded into areas that used to be rural and covered with vegetation. When more people live in tight urban concentrations, it often marks the beginning of city sprawl.

The Land Use/Land Cover (LULC) map from 2023 stands out with clarity. In most areas of Tangail Pourashava, urban land is now the most common type of land cover. The central and nearby regions have mostly been turned red, leaving little space for farms and natural vegetation near the edges. There is now less spread of bare land and water bodies than before, making them more confined. As a result, more natural and agricultural land is being developed into covered areas, leading to less diversity and more substantial environmental risks.

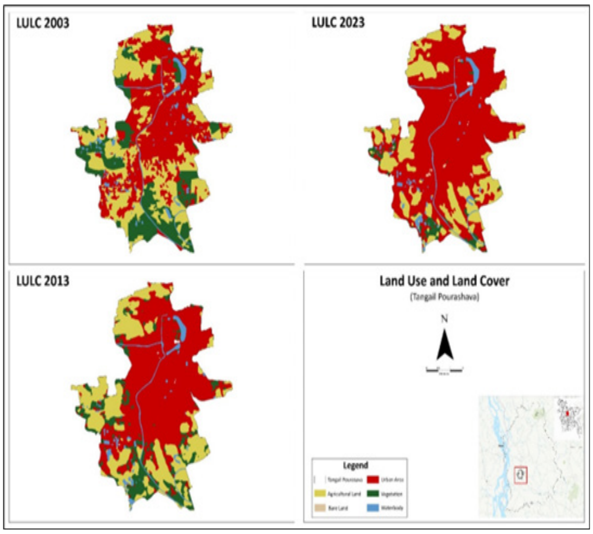

Figure 3. Temporal Land Use and Land Cover Changes maps (2003-2023) showing urban expansion and the decline of other land use categories in Tangail Pourashava.

Several variables have led to these changes. Most important is the rapid and often unexpected growth of cities, because this increases the need for houses, offices, and roads, turning land that grew crops or plants into urban areas. Due to less money earned in agriculture and rising land value in cities, farmers are turning to building projects. Causes such as floods, dramatic weather can render the land useless for farming, leading to its quick abandonment and use for cities instead. Since there are weak land regulations and those rules are not well applied, more land is being changed without control.

The results of LULC changes are significant and can be seen in many ways. Immediately, urban heat intensifies as vegetation declines and impervious surfaces expand, known as the urban heat island effect. Increasing temperatures are bad for how comfortable people feel, their health, and increase the need for energy to keep places cool. Shrinking agricultural land cuts down on local food supplies and makes farming harder, possibly resulting in more people leaving villages and having unsettled incomes. At the same time, lowering the area of forests and natural water bodies diminishes services such as controlling flooding, replenishing groundwater, and supporting various life forms, increasing the city's sensitivity to environmental risks.

From 2003 to 2023, Tangail Pourashava experienced rapid urban development at the expense of its natural resources. When agricultural and natural landscapes are converted into urban areas, it creates significant environmental, social, and economic pressures. Local officials, municipalities, and planners must adopt sustainability in all land use, use green infrastructure, and enforce strong zoning policies to maintain a balance with nature and the environment.

3.1.2 Comparative Analysis of Land Use and Land Cover (LULC) in Tangail Pourashava

Over the past twenty years, there has been a significant change in how land is used within Tangail Pourashava. The graph (Figure 4) demonstrates that cities have grown significantly, from 1,200 hectares in 2003 to 1,550 hectares in 2013, reaching almost 1,900 hectares in 2023. The increase in urban dwellers is probably due to more people, the creation of new infrastructure, and economic changes. In contrast, there has been a slow yet apparent decrease in both types of land. From its peak in 2003, covering around 900 hectares, agricultural land fell to roughly 600 hectares in 2023, indicating that much of the land was turned into urban areas.

Conversely, agricultural land decreased from approximately 900 hectares in 2003 to 600 hectares in 2023, while vegetation area, covering over 500 hectares in 2003, shrank to around 300 hectares in 2013 and even less than 100 hectares by 2023. A decrease in green spaces indicates that wild animals and different plant species could be losing their homes, and it also raises doubts about higher surface temperatures and weaker protection of cities from climate impacts.

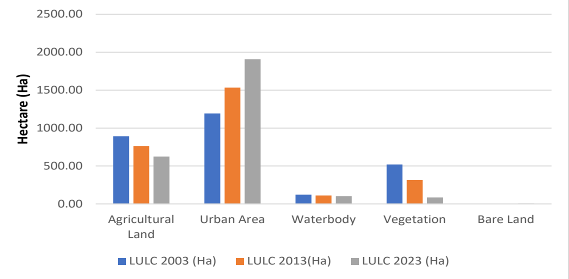

Figure 4. Comparison of LULC categories (2003-2023) in hectares of total Tangail Pourashava.

The extent of waterbodies remained relatively stable, usually staying close to 100 hectares, which may result from natural care or strict regulations. This figure (Figure 4) highlights that cities tend to take over agriculture and plant cover as they expand. This situation represents the effects of fast urban growth and the destruction of sparsely populated lands. The outcomes suggest that local planning and policies for land use must be designed to support both development and protection of the environment, especially in growing places like Tangail Pourashava.

3.1.3 Land Use and Land Cover (LULC) Change Matrix in Tangail Pourashava

3.1.3.1 Specific and Relative Percentage Analysis

Table 4 demonstrates how the landscape of Tangail Pourashava has changed from 2003 to 2023. The numbers indicate that cities are growing and replacing farmland and greenery. The most significant change recorded was the transformation of 417.63 hectares of farmland to urban space. It illustrates the stress that rural areas experience when people move to cities. About 341.05 hectares of land used for vegetation were converted into urban areas, resulting in 12.49% of the specific change and 33.65% of the relative change. These two changes account for approximately 75% of all land transformations, showing how quickly urban areas form.

Table 4. Land Use and Land Cover Transition Matrix of Tangail Pourashava (2003–2023): Specific and Relative Percentage Analysis

Year (2003)	Year 2023	Area (Hectare)	Specific Change (%)	Relative Change (%)
Agricultural Land	Agricultural Land	450.82	0	0
Agricultural Land	Bare Land	1.41	0.05	0.14
Agricultural Land	Urban Area	417.63	15.3	41.21
Agricultural Land	Vegetation	10.30	0.38	1.02
Agricultural Land	Waterbody	16.71	0.61	1.65
Bare Land	Bare Land	2.91	0	0
Urban Area	Urban Area	1117.41	0	0
Urban Area	Agricultural Land	56.20	2.06	5.54
Urban Area	Bare Land	4.01	0.15	0.4
Urban Area	Vegetation	1.67	0.06	0.16
Urban Area	Waterbody	9.30	0.34	0.92
Vegetation	Vegetation	64.82	0	0
Vegetation	Agricultural Land	107.61	3.94	10.62
Vegetation	Bare Land	0.57	0.02	0.06
Vegetation	Urban Area	341.05	12.49	33.65
Vegetation	Waterbody	5.68	0.21	0.56
Waterbody	Waterbody	80.25	0	0
Waterbody	Agricultural Land	13.64	0.5	1.35
Waterbody	Bare Land	0.15	0.01	0.01
Waterbody	Urban Area	25.57	0.94	2.52
Waterbody	Vegetation	2.03	0.07	0.2

Table 4. Land Use and Land Cover Transition Matrix of Tangail Pourashava (2003–2023): Specific and Relative Percentage Analysis.

Furthermore, other notable changes include farming replacing 107.61 ha of greenery, 56.20 ha of urban territory becoming farmland, and 25.57 ha of previously existing water bodies being transformed into urban zones. These transitions result from a mixture of land use demands, which may include illegal building, changes in farming, or environmental changes. Shifts such as from the city to an open area, from vegetation to bare land, or from water to vegetation or open land is each less than 1% of the overall or relative changing. They suggest that local areas are shifting or degrading because of certain human activities.

The evaluation highlights two crucial measurements. It represents how much of the study area changed, compared to the total area. On the other hand, relative change (%) only looks at the portion of land that changed and tells the ratio of each type of change there. It highlights the amount of change and which changes drove the process. Furthermore, much agricultural and vegetative land has been transformed into cities, suggesting that urban growth continues. Because of this fast urbanization, better urban planning and control over land use in Tangail Pourashava are important.

3.1.4 The Land Use and Land Cover (LULC) Transitions

The map (Figure 5) displays the changes in land use and cover over time for Tangail Pourashava from 2003 to 2023. What stands out most is the growing number of urban areas built on agricultural and vegetative land, with the central and southwestern regions undergoing the most conversion. With its growth, the city has turned green spaces into urban areas for housing and development.

The map (Figure 5) shows where water bodies and vegetation replaced farmland, likely caused by natural processes and people making changes. Areas covered in darker shades show areas where the landscape, vegetation, and waterbodies have not changed, despite other shifts. It also represents that urbanization is increasing and that the city is changing at various speeds and intensities. The results emphasize how crucial it is to manage development and the environment together.

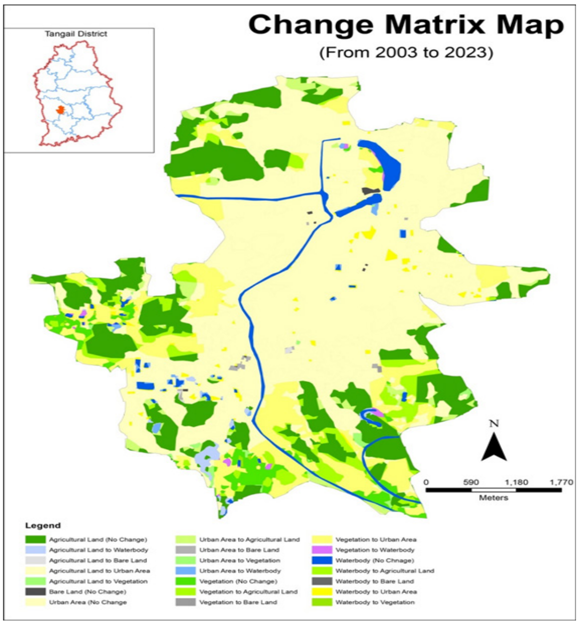

Figure 5. LULC transition map illustrating conversions among land-use categories (2003-2023).

3.1.5 Gradient Direction of Urban Area Expansion (2003-2023)

The gradient direction shows how the urban area grew over time by comparing gradient direction maps and radar charts from 2003 to 2023. It can be seen in Figure 6 that over time, around 2003, 2013, and 2023, the city grew more outward in specific directions. Among the eight directions, the North (N), Northeast (NE), East-Northeast (ENE), and Southwest (SW) have experienced the most significant growth in cities in the past two decades. The rate of area change has slowly increased from 2003 to 2023, showing that there has been a continuous trend of expansion over the years.

Figure 6, which demonstrates the extent of urban areas using a radial layout, supports this pattern seen from 2003 to 2023. The map reveals that the city has grown out from the center and is now dominant in the SW, N, NE, and E areas. Lighter shades of blue in 2003 are concentrated mainly around the center, and the vegetation land in 2023 are primarily found in the outer rings and the eight mentioned directions. This area's development seems to be concentrated centrally while expanding outwards near urban boundaries because of infrastructure, land availability, and specific growth regions.

The pattern of urban expansion is lopsided, showing that cities are growing at different rates in different directions. Growth in these directions shows that people followed important routes, roads, or economic zones to move out. At the same time, WNW, NW, and SE directions have weak growth, mainly due to unnecessary barriers that stop development, like rivers or not enough roads and buildings. The findings clearly show that urban development takes specific paths, and some regions experience rapid development while others remain underdeveloped.

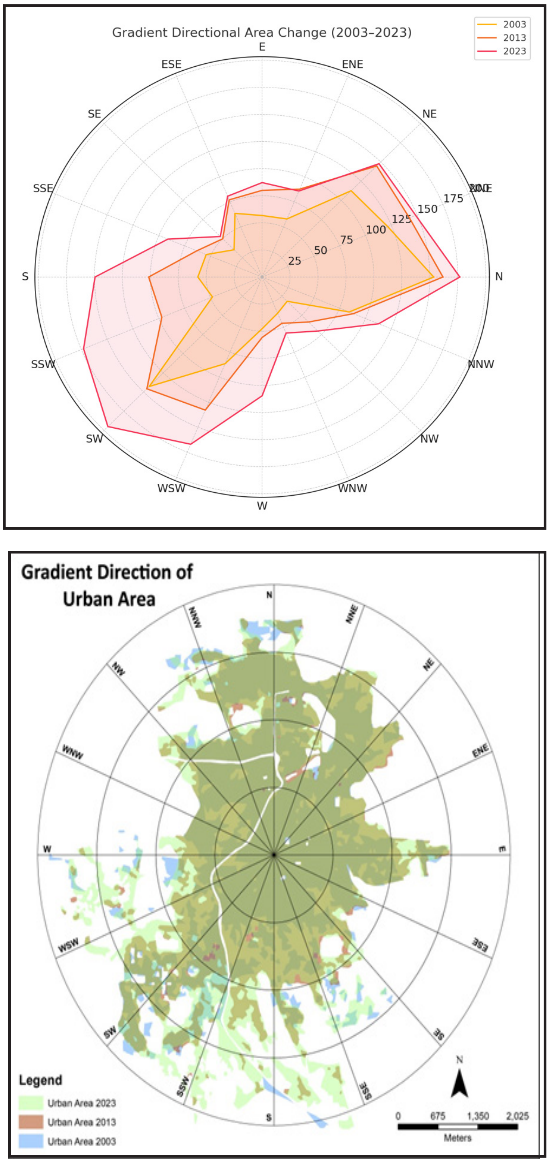

Figure 6. Gradient-direction (sectoral) analysis of urban expansion, derived from 16 radial sectors (2003–2023).

Such observations are significant for people who plan and manage cities, as they pinpoint places where more care should be taken in handling urban needs. In addition, knowledge of these patterns can assist with making future land-use, zoning, and sustainability policies. Overall, this technique can ensure innovative growth and development and support plans for cities that grow quickly.

3.2 Spatiotemporal Variation of Land Surface Temperature (LST) in Tangail Pourashava

LST data (figure 7) reveal a striking rise in Tangail Pourashava from 2003 to 2023, alongside a growing UHI effect. In 2003, the Pourashava mostly fell from 25°C to 29.75°C, as measured by LST. The red patches or high-temperature zones were less frequent and often found only in the north and south parts of the map.

From 2013, there was a noteworthy increase in the area and severity of intensive heating. Areas with LST above 30°C grew more common, especially in the center and

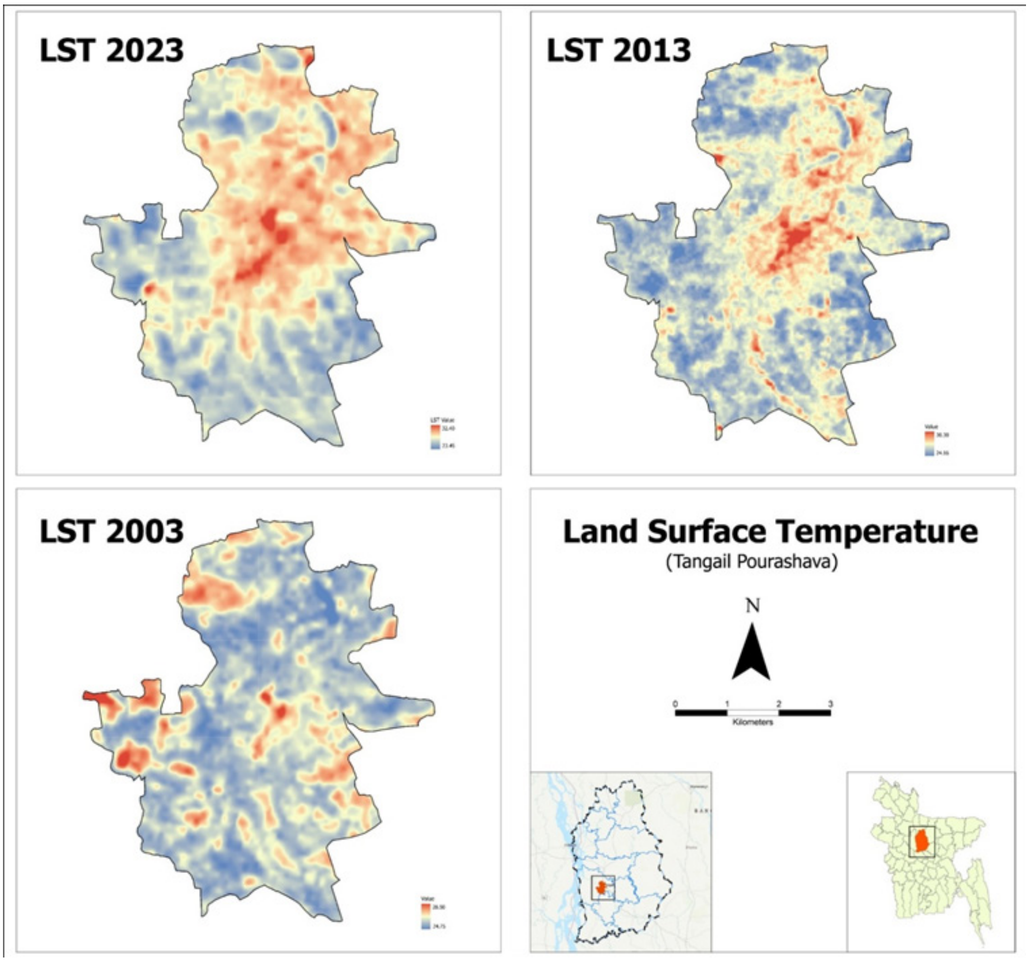

Figure 7. Spatiotemporal Variation of Land Surface Temperature (LST) in Tangail Pourashava (2003 to 2023).

northeast of Tangail Pourashava. Over this decade, the proportion of urbanization increased, resulting in less green and open space and raising the region's average temperature. The grouping of high temperatures in space during this period hints at the start of a UHI.

In 2023, temperature changes accelerated. Temperatures were often very high in the main urban regions, reaching 30°C or more in many parts. At the same time, large portions of the cooler surfaces that were once common in 2003 now existed only in limited peripheral locations on the outskirts. Urban construction and a decrease in trees have caused built-up areas to become hotter than nearby regions.

Over the course of two decades, Tangail Pourashava gradually developed from a semi-urban area with a balanced temperature to an urban area with high heat. The growth in impervious areas, the loss of land cover, and the rise in heat from vehicles and industries are why LST is increasing. This increase results from quick development within the city and links to the overall rise in temperature because of the changing global climate.

Its effects are wide-ranging. As the Earth's surface warms, many people, especially those already vulnerable, are likely to suffer from heat-related problems. Crop production may be worsened by heat, while the groundwater supply is threatened if evapotranspiration accelerates atmospheric moisture loss from rivers and lakes. In addition, the effect of the UHI worsens with time, increasing the challenges for public health and managing the environment.

3.2.1 Temporal variation in Maximum and Minimum Land Surface Temperatures in Tangail Pourashava

Figure 8 highlights the differences in maximum and minimum Land Surface Temperatures (LST) from 2003 to 2023 in Tangail Pourashava. The data shows an increase in maximum LST over the past twenty years. 2003 the temperature peaked at about 29°C, increasing to around 31°C in 2013 and then further to 33°C by 2023. There is evidence that the high temperatures are increasing due to the urban heat effect caused by Rapid City development, expansion of built-up areas, and reduction of natural vegetation.

On the other hand, the minimum LST followed a different pattern. In 2003, the temperature was about 25°C, but in 2013 it went up to 25.5°C. By 2023, the temperature dropped again to around 24°C. As the maximum temperature goes up and the minimum temperature goes down, it seems like the difference between daytime and nighttime temperatures is becoming bigger. As the gap widens, the city's thermal variation increases.

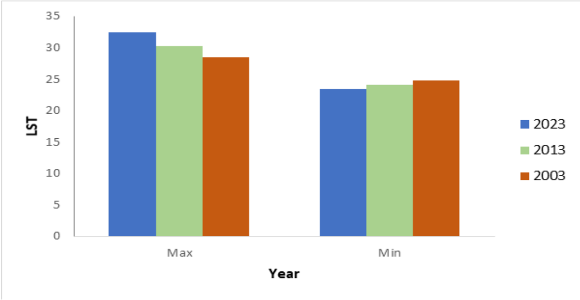

Figure 8. Temporal trend of Maximum and Minimum LST between 2003 and 2023.

Tangail Pourashava is undergoing a significant shift in its weather and climate. With summers and cold seasons worsening, cities must implement sustainable development strategies. Building green infrastructure, saving natural vegetation, and following climate-friendly urban planning can reduce the growing heat in cities and strengthen their protection from the effects of climate change.

3.3 Correlation between Land Surface Temperature and Land Use and Land Cover types in Tangail Pourashava

Figure 9 shows the correlation between LST and important LULC classes in Tangail Pourashava. There appears to be a strong and clear link between temperature and different land cover types.

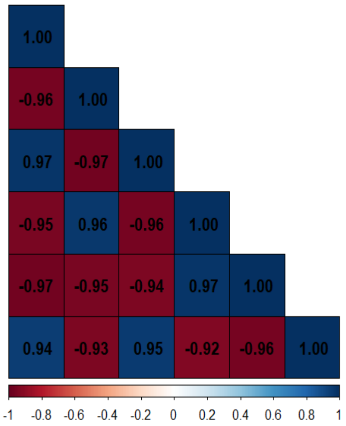

Figure 9. Correlation Matrix between Land Surface Temperature and Major Land Use Land Cover (LULC) Types in Tangail Pourashava.

As urban areas get larger, they cause a corresponding increase in temperature. Similarly, bare land and high temperatures are strongly related (r = 0.94), suggesting that exposed surfaces without plants intensify heat by absorbing much more energy than other objects.

Alternatively, vegetation, water, and agricultural areas do not rise in temperature; they exhibit a strong negative correlation (r = -0.95 to -0.97). As a result, these land cover types help keep the temperature down by releasing water through evapotranspiration and giving shade. Urbanization and shrinking land areas help increase land temperatures. The correlation analysis indicates that urban areas and agricultural land have a strong negative bond (r = -0.97), confirming that agrarian regions are converted into urbanized zones. In the same way, urban expansion limits vegetation (r= -0.94) and waterbodies (r= -0.96), leading to a significant loss of natural land cover. The presence of vegetation and waterbodies goes together and provides higher cooling effects when they are present together (correlation of 0.97).

The correlation matrix demonstrates how LULC changes affect thermal patterns. The growth in cities and cleared land is strongly connected to higher LST. Still, having plants, water, and farms helps reduce the heat caused by urban living. Green infrastructure and careful land use are vital in decreasing the urban heat in Tangail Pourashava.

4. Discussions

The research highlights substantial changes in the land use and heat environment of Tangail Pourashava from 2003 to 2023, proving how fast urbanization affects LST. Around 58% of the urban area expansion occurred by converting fields and green spaces into built-up areas. During this period of spatial expansion, the land surface temperature (LST) increased noticeably, reaching almost 33°C by 2023, compared to 29°C in 2003. These results are consistent with observations from other South Asian cities, including Dhaka, Khulna, and Chittagong, where the lack of proper urban planning has contributed to greater temperature variation between urban and rural areas (Dewan et al., 2021; Rashid et al., 2022; Imran et al., 2021). Interestingly, the prominent major cities do not usually show the most risk, but smaller secondary cities such as Tangail that face comparable challenges.

There is a strong connection between LST and changes in land use. Cities and land without vegetation had strong links with high LST, which suggests that they accumulate heat due to increased urbanization. Vegetation, agricultural land, and waterbodies had strong negative correlations (r= –1.00) with heat spikes because they help cool the land by evapotranspiration and shading (Sobrino, 2013; Zhang et al., 2021). Building more, which leads to land cover changes, causes heat to increase and reduces the environment's resilience in cities. The main directions of urban growth point toward the northeast, east-northeast, and the southwest. This indicates how urban sprawl changes each year, depending on the layout and accessibility of nearby infrastructure.

This study offers a valuable contribution to the field and carries important policy implications. Rising atmospheric heat poses challenges to human well-being, particularly in areas with limited or no access to air conditioning, as well as to agriculture and water resources. When daytime peak temperatures increase more sharply than nighttime lows, it typically signals stronger urban heat island effects, which can lead to higher energy consumption, greater health risks, and deteriorating urban living conditions (Johansson & Emmanuel, 2006; Kim & Noh, 2024). To act swiftly and limit the effects of such risks, urban greening, saving vegetated buffers, using reflective roofs and permeable pavements, and strict zoning guidelines are needed.

However, the report has some shortcomings. Landsat images help look at long-term changes, but cannot show close-up variations in surface thermal patterns. Adding more detailed remote sensing imagery, such as Sentinel-2 and UAV thermal data, can help us identify fine-grained city changes (Voss et al., 2013; Chu et al, 2024). The lack of socio-economic or demographic data makes it challenging to explore differences in how groups are affected by climate hazards. To better understand climate vulnerability and resilience, using GIS methods and interviewing stakeholders and households is recommended (Williams et al., 2020; Bobiec et al., 2021).

This research offers important insights into the environmental and thermal consequences of urban expansion in a rapidly developing secondary city. It underscores the urgency of promoting sustainable and climate-responsive urban growth in Tangail, while also providing a practical framework applicable to other cities across the Global South. To mitigate the escalating impacts of the Urban Heat Island effect and enhance urban resilience, planners should integrate land use planning with nature-based solutions as a core element of future urban governance.

5. Conclusion

The researchers examined LULC changes and their effect on LST in Tangail Pourashava over 20 years. Findings revealed a significant change in urban space expansion, resulting in increased surface temperature. Between those years, LST increased from about 29 °C to 33 °C, and vegetation and cultivable land experienced significant cutbacks. Urban growth and the large UHI effect can be seen in the more densely populated central areas. The study also revealed a clear pattern, showing a strong relationship between land cover and temperature changes. Increased LST appears to be associated with expanding urban and barren places, whereas vegetation, agricultural areas, and water bodies help keep the city cooler. Also, the direction of urban growth towards the northeast and southwest may be shaped by access to infrastructure and land market changes, which could lead to increased thermal vulnerability in specific locations.

Targeted policy interventions are essential to regulate unplanned and conversion and strengthen urban resilience. Lands being used without limits and lowering natural protection systems are causing greater risks to the environment and health. Supporting these trends should involve creating green infrastructure, enforcing environmentally friendly zoning, and choosing urban designs to handle climate change. It has been found that remote sensing and GIS approaches help monitor ecosystems in urban regions, especially where data is limited. Future studies should consider detailed pictures, economic information, and joint engagement of citizens, as this can help us identify the equity issues of urban heating risk and plan adaptations that benefit all city users. Ultimately, the ongoing land transformation and effects of climatic stress in Tangail Pourashava display the relationship between the two in secondary cities. Findings of this study support the ongoing research on urban heat and land changes in developing countries. It also gives a consistent structure for examining how sustainable environments are in fast-developing cities across the globe.

Conflicts of Interest: The authors express no conflict of interest.

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