

# Spatio-Temporal Analysis of Vegetation Decline and Its Impact on Land Surface Temperature and Urban Heat Island Intensification in English Bazar Municipality, West Bengal (2001–2025)

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**Abstract-** Rapid urbanization and land surface transformations significantly influence local thermal environments, leading to the intensification of Urban Heat Island (UHI) effects. This study analyses the spatio-temporal relationship between vegetation dynamics and Land Surface Temperature (LST) in English Bazar Municipality (EBM), West Bengal, over the period 2001–2025 using multi-temporal satellite data. The results indicate a consistent decline in vegetation cover, accompanied by a substantial increase in surface temperature. The mean LST increased from approximately 30.43°C in 2001 to 40.41°C in 2025, reflecting pronounced thermal intensification. A strong inverse relationship between NDVI and LST is observed, with low vegetation areas corresponding to higher temperatures. High-temperature zones have expanded notably in the central and eastern parts of the municipality, indicating the growth of UHI hotspots. The study demonstrates that vegetation loss and urban expansion are key drivers of rising surface temperature and UHI intensification, highlighting the need for climate-responsive urban planning and increased green cover to mitigate future thermal stress.

**Keywords –** Vegetation Dynamics, Land Surface Temperature (LST), Urban Heat Island (UHI), Urbanization.

## I. INTRODUCTION

Urbanization is a major driver of environmental transformation, particularly in rapidly growing regions of India. The replacement of natural vegetation with impervious surfaces alters the surface energy balance, increasing heat absorption while reducing evapotranspiration, thereby contributing to the formation of Urban Heat Islands (UHI) [8].

Vegetation plays a critical role in regulating urban microclimates. The Normalized Difference Vegetation Index (NDVI) is widely used to quantify vegetation density, while Land Surface Temperature (LST) derived from satellite data provides a reliable indicator of surface thermal conditions. Numerous studies have demonstrated a strong inverse relationship between NDVI and LST, indicating that vegetation loss significantly contributes to increased surface temperatures [15].

In eastern India, particularly in Malda district, long-term studies have reported a consistent warming trend associated with urban expansion and land surface changes [9]. However, most studies are limited in temporal scope or lack detailed vegetation–temperature interaction analysis at the municipal scale. This study addresses this gap by conducting a long-term NDVI–LST analysis for English Bazar Municipality.

## II. STUDY AREA

English Bazar Municipality (EBM), located in Malda district of West Bengal, India, lies within the Gangetic alluvial plains along the eastern bank of the Mahananda River [3]. The municipality extends geographically between approximately 24°59'N to 25°02'N latitude and 88°07'E to 88°10'E longitude (Fig. 1), forming part of the lower Gangetic basin [11]. It serves as a major urban and commercial center in North Bengal and has experienced rapid urban expansion in recent decades [7]. The population of English Bazar increased from 176,991 in 2001 to 205,521 in 2011, indicating significant urban growth during the intercensal period [7]. This population increase reflects intensified land-use transformation and expansion of built-up areas within the municipality.

The study area exhibits a heterogeneous urban landscape, with dense built-up development concentrated in the central core, particularly around Rathbari, Malda Town railway station, and adjoining commercial zones. The eastern sector, including Mokdumpur, reflects recent urban growth, while relatively higher vegetation cover is observed in peripheral regions such as Maheshmati and along the Mahananda River [3]. The region experiences a tropical monsoon climate characterized by hot summers, high humidity, and mild winters [4]. The mean

annual temperature ranges between 25°C and 27°C, with summer temperatures frequently exceeding 35–40°C during pre-monsoon months, while winter temperatures may decline to 10–15°C [4, 9]. Long-term observations indicate a gradual warming trend of approximately 0.006–0.007°C per year, largely attributed to urbanization and land surface modifications [2].

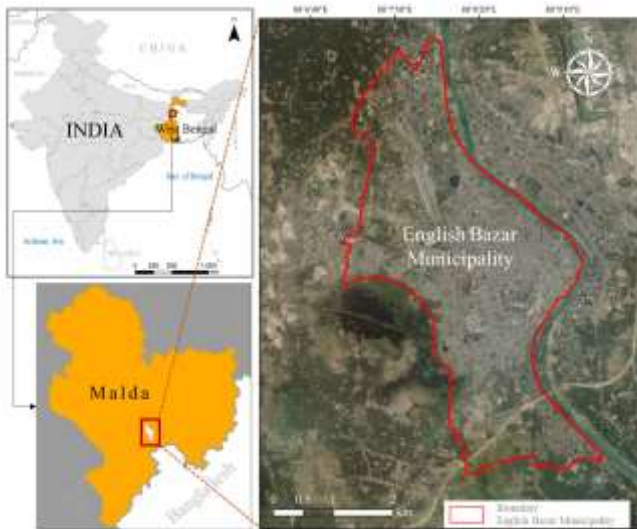


Fig.1. Location map of English Bazar Municipality, Malda district, West Bengal, India

The distinct contrast between densely built-up urban areas and relatively vegetated peripheral zones, combined with ongoing urban expansion, makes English Bazar Municipality a suitable setting for analyzing vegetation–temperature interactions and the development of Urban Heat Island (UHI) effects [8, 15].

### III. MATERIALS AND METHODS

#### Data Source

This study utilizes Landsat Collection 2 Level 2 (L2C2) surface reflectance and surface temperature products obtained from the U.S. Geological Survey [12]. The study area corresponds to Landsat Path 138 and Row 043.

Table I. Landsat Data used in the study

| Year | Satellite   | Sensor | Season       | Purpose |
|------|-------------|--------|--------------|---------|
| 2001 | Landsat 4–5 | TM     | Post-monsoon | NDVI    |
| 2001 | Landsat 4–5 | TM     | Pre-monsoon  | LST     |
| 2011 | Landsat 4–5 | TM     | Post-monsoon | NDVI    |
| 2011 | Landsat 4–5 | TM     | Pre-monsoon  | LST     |

|      |             |          |              |      |
|------|-------------|----------|--------------|------|
| 2025 | Landsat 8–9 | OLI/TIRS | Post-monsoon | NDVI |
| 2025 | Landsat 8–9 | OLI/TIRS | Pre-monsoon  | LST  |

#### NDVI Calculation and Interpretation

The Normalized Difference Vegetation Index (NDVI) was derived from Landsat Collection 2 Level 2 surface reflectance data using the standard formulation,  $NDVI = (NIR - Red) / (NIR + Red)$ , where NIR and Red correspond to the near-infrared and red spectral bands, respectively [14, 15]. The index provides a normalized measure of vegetation density, with values ranging from -1 to +1, where higher values indicate dense and healthy vegetation, while lower values represent sparse vegetation, bare soil, or built-up surfaces [1].

Post-monsoon imagery was selected for NDVI computation to capture peak vegetation conditions and minimize seasonal variability, thereby ensuring temporal consistency across the study years [6]. The application of NDVI as a proxy for vegetation condition is well established in urban environmental studies, where it serves as a reliable indicator of surface biophysical characteristics [15].

In addition to assessing vegetation cover, NDVI was further utilized as an indirect indicator of built-up expansion. Areas consistently exhibiting low NDVI values were interpreted as non-vegetated or impervious surfaces, including roads, rooftops, and other urban infrastructure [16]. Consequently, a temporal decline in NDVI values was considered indicative of both vegetation loss and the expansion of built-up areas, a relationship commonly observed in rapidly urbanizing regions [15].

For analytical clarity, NDVI values were classified into distinct categories representing different land cover conditions (Table 1). This classification facilitated the differentiation between vegetated and non-vegetated surfaces and enabled a more comprehensive understanding of landscape transformation [15]. Areas falling within the lower NDVI range (0.0–0.2) were interpreted as built-up or urbanized zones, whereas higher NDVI values corresponded to varying densities of vegetation cover [16]. The observed shift of pixels from higher NDVI classes to lower classes over time indicates a transition from vegetated surfaces to built-up areas, thereby confirming the spatial expansion of urban land within the study area [15].

Table II. NDVI Classification and Interpretation

| NDVI Range | Land Cover Type      | Interpretation                                      |
|------------|----------------------|---|
| < 0.0      | Water bodies         | Strong absorption of NIR, no vegetation [1]         |
| 0.0 – 0.2  | Built-up / Bare land | Impervious surfaces, urban areas, exposed soil [16] |

|           |                     |   |
|-----------|---------------------|---|
| 0.2 – 0.4 | Sparse vegetation   | Grassland, degraded vegetation [15]     |
| 0.4 – 0.6 | Moderate vegetation | Agricultural land, mixed vegetation [6] |
| > 0.6     | Dense vegetation    | Forest or high biomass vegetation [1]   |

**LST Derivation (L2C2-Based)**

Land Surface Temperature (LST) was derived from the surface temperature bands available in the Landsat Collection 2 Level 2 (L2C2) dataset, which provides atmospherically corrected and emissivity-adjusted thermal products [12]. The use of L2C2 data ensures radiometric consistency and eliminates the need for additional atmospheric correction, thereby improving the reliability of thermal analysis [12].

For Landsat L2C2 products, surface temperature (ST) is provided as a scaled digital number (DN), which was converted to Kelvin using the USGS-recommended rescaling equation,  $ST = (DN \times 0.00341802) + 149.0$  [12]. The resulting values were then converted to degrees Celsius using the relation,  $LST (^{\circ}C) = ST - 273.15$ , to enable meaningful interpretation of thermal conditions.

Pre-monsoon imagery was selected for LST estimation in order to capture peak thermal conditions, as this period is characterized by maximum surface heating and minimal vegetation moisture influence, making it particularly suitable for assessing Urban Heat Island intensity [15]. The use of seasonally consistent datasets enhances comparability across years and improves the detection of long-term thermal trends [6].

**UHI Identification**

Urban Heat Island (UHI) zones were identified based on the statistical distribution of LST values across the study area. Areas where LST exceeded the mean temperature by at least one standard deviation were classified as UHI hotspots, representing zones of elevated thermal intensity [8]. This threshold-based approach is widely applied in urban climate studies to distinguish thermally anomalous regions from their surroundings [15].

The spatial distribution of these high-temperature zones was mapped to identify the extent and intensity of UHI within English Bazar Municipality. This approach enables the identification of core urban hotspots as well as emerging thermal zones associated with ongoing urban expansion [13].

**NDVI–LST Relationship**

The relationship between NDVI and LST was examined through spatial comparison and statistical interpretation to assess the interaction between vegetation cover and surface temperature. A strong inverse relationship was observed,

wherein areas characterized by low NDVI values correspond to higher LST, while areas with higher NDVI exhibit relatively lower temperatures [15]. This negative correlation reflects the role of vegetation in regulating surface temperature through evapotranspiration and shading, whereas built-up and non-vegetated surfaces tend to absorb and retain heat, resulting in elevated thermal conditions [1]. The observed relationship provides a robust basis for understanding the role of vegetation decline in driving Urban Heat Island intensification within the study area [15].

**IV. RESULTS AND DISCUSSION**

**NDVI-Based Evaluation of Vegetation Change and Urban Expansion**

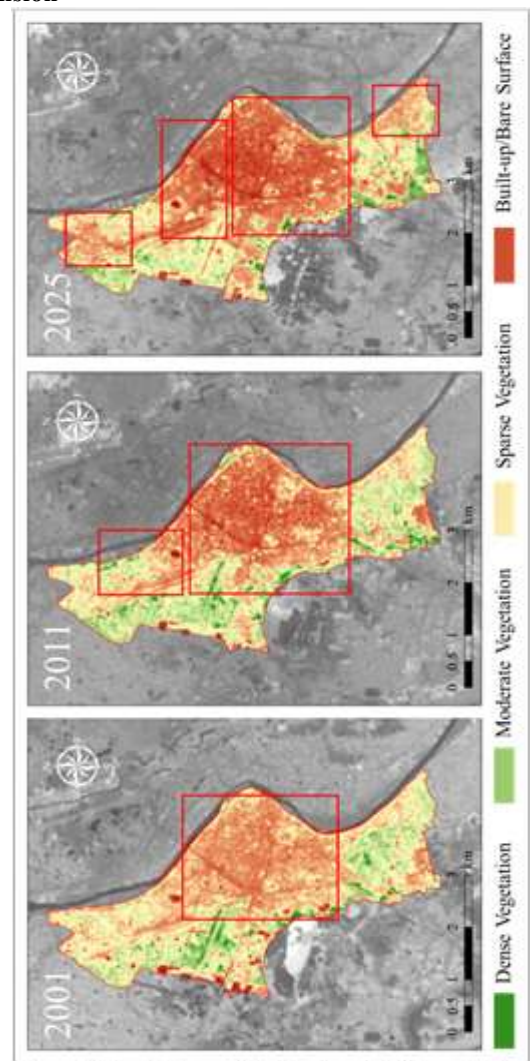


Figure 2. Spatio-temporal distribution of the Normalized Difference Vegetation Index (NDVI) in English Bazar Municipality for the years 2001, 2011, and 2025, illustrating

the progressive decline in vegetation cover and expansion of low NDVI (built-up) areas. Highlighted regions indicate zones of significant vegetation loss and urban expansion over time.

By 2011, a noticeable decline in vegetation cover is observed, accompanied by increasing fragmentation of vegetated patches. The central and eastern parts of the municipality, particularly around Rathbari and the Malda Town railway station corridor, exhibit a clear expansion of low NDVI zones. The highlighted regions indicate a shift from moderate vegetation to sparse or non-vegetated surfaces, reflecting progressive urban expansion. At the same time, vegetation remains relatively concentrated in the southern and southwestern parts, especially near Maheshmati and river-adjacent areas.

In 2025, the decline in vegetation becomes more pronounced, with a substantial increase in areas characterized by low NDVI values. The central, eastern, and northeastern parts of the municipality are dominated by sparse vegetation or built-up surfaces, indicating extensive urbanization. This transformation is closely associated with rapid population growth, as the population of English Bazar may be considered to approach approximately 0.30 million by 2025; if such growth is assumed relative to the 2011 Census level, it would represent an expansion of approximately ~46% [7]. The highlighted zones clearly demonstrate the spatial expansion of low NDVI regions, particularly in Mokdumpur and adjoining urban growth corridors. Although some vegetation persists in the southern fringes, these areas also show signs of degradation and fragmentation.

Overall, the temporal trend indicates a consistent shift from higher NDVI classes to lower NDVI classes, signifying vegetation loss and expansion of impervious surfaces. This transformation reflects rapid urban growth within the municipality and provides a strong basis for understanding the observed increase in land surface temperature and the intensification of Urban Heat Island (UHI) effects.

### Spatio-Temporal Trends of Land Surface Temperature (LST)

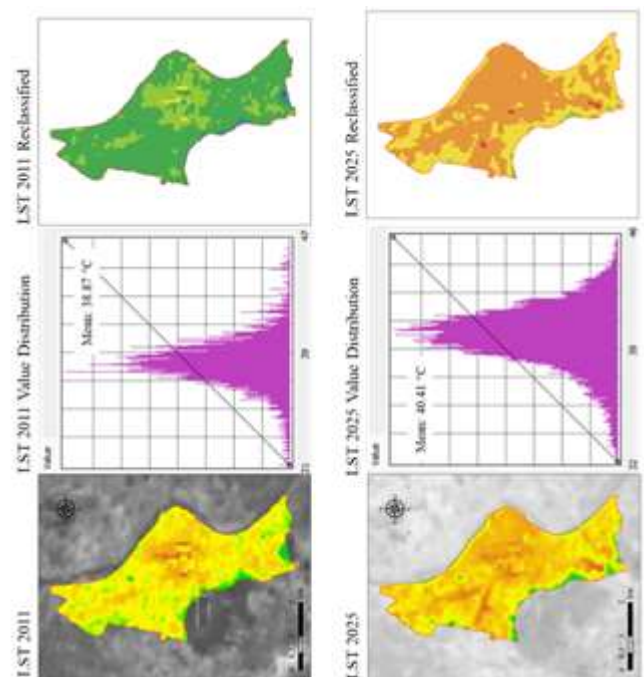
The spatio-temporal analysis of Land Surface Temperature (LST) reveals a significant increase in surface thermal intensity across English Bazar Municipality over the study period (2001–2025). The LST distribution indicates a consistent shift towards higher temperature ranges, reflecting progressive thermal intensification.

In 2001, the study area was predominantly characterized by moderate temperature conditions, with LST values largely concentrated within the range of 25°C to 35°C. The mean LST was estimated at 30.43°C, indicating relatively stable thermal conditions. Spatially, lower temperature zones were observed in the southern and peripheral regions, particularly near vegetated areas and water bodies along the Mahananda River.

In contrast, moderately higher temperatures were already evident in the central urban core, suggesting the early stages of urban-induced thermal effects.

By 2011, a noticeable increase in surface temperature is observed, with the mean LST rising to 38.87°C. The spatial distribution indicates a clear expansion of high-temperature zones, particularly in the central and eastern parts of the municipality. Areas that previously exhibited moderate temperatures transitioned into higher temperature classes (35°C–45°C), indicating intensified surface heating. The histogram distribution further reflects this shift, with a greater concentration of pixels in higher temperature ranges. This change corresponds with increased urban development and reduction in vegetative cover.

In 2025, the thermal conditions become significantly more pronounced, with the mean LST reaching 40.41°C, indicating a substantial increase of approximately 10°C compared to 2001. High and very high temperature zones (above 35°C) dominate the study area, particularly in the central, eastern, and southeastern regions (Fig. 3). The classified LST map shows a widespread expansion of areas falling within the 40°C–50°C range, reflecting intense surface heating. The histogram distribution further confirms this trend, showing a rightward shift towards higher temperature values.



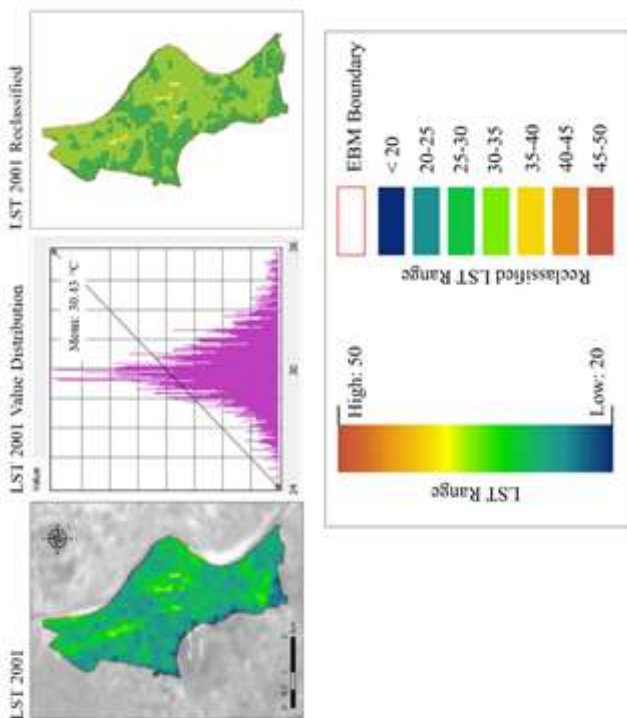


Figure 3: Spatio-temporal distribution and classification of

Land Surface Temperature (LST) in English Bazar Municipality for the years 2001, 2011, and 2025, along with corresponding histogram distributions.

Spatially, the most prominent high-temperature zones are concentrated around Rathbari, Malda Town railway station, and Mokdumpur, where dense built-up structures and reduced vegetation contribute to increased heat retention. In contrast, relatively lower temperatures persist in the southern and southwestern fringes, including areas near Maheshmati and along the Mahananda River, where vegetation cover remains comparatively higher. The temporal trend demonstrates a clear and consistent increase in LST consecutively, accompanied by the expansion of high-temperature zones across the municipality. This pattern indicates the intensification of Urban Heat Island (UHI) effects, driven by rapid urbanization and the decline of vegetation cover (Fig. 3). The strong correspondence between spatial patterns of elevated LST and low NDVI areas further reinforces the role of land surface changes in shaping urban thermal environments.

#### Relationship between NDVI and LST

A strong inverse relationship between NDVI and LST is observed across all study years, indicating that vegetation plays a crucial role in regulating surface temperature. Areas characterized by low NDVI values consistently correspond to higher LST, while regions with higher NDVI exhibit comparatively lower temperatures (Fig. 2 and Fig. 3).

This negative correlation is consistent with established findings in urban climate studies, where vegetation reduces surface temperature through evapotranspiration and shading, thereby mitigating heat accumulation [1, 15]. In contrast, built-up surfaces and impervious materials tend to absorb and retain heat, leading to elevated thermal conditions [13].

The spatial correspondence between declining NDVI and increasing LST observed in this study indicates that vegetation loss is a primary driver of thermal intensification in English Bazar Municipality. The conversion of vegetated land into built-up areas reduces surface moisture and increases heat storage, thereby enhancing Urban Heat Island (UHI) effects. Similar relationships have been reported in several urban environments, reinforcing the robustness of NDVI–LST interactions as an indicator of urban thermal dynamics [15].

#### Spatial Distribution of Urban Heat Island (UHI)

The spatial distribution of high LST zones reveals a distinct pattern of Urban Heat Island (UHI) formation within English Bazar Municipality. As shown in Fig. 3, the most intense UHI zones are concentrated in the central urban core, particularly around Rathbari, the Malda Town railway station area, and adjacent commercial corridors, where dense built-up structures dominate and vegetation cover is minimal. The eastern region, including Mokdumpur, exhibits a significant expansion of high-temperature zones over time, indicating rapid urban growth and increasing impervious surface coverage. These areas show a clear transition from moderate to high LST classes, reflecting ongoing land surface transformation.

The north-central part of the municipality is emerging as a transitional thermal hotspot, where increasing urban development is gradually altering the thermal landscape. In contrast, comparatively lower temperatures are observed in the southern and southwestern regions, particularly around Maheshmati and along the Mahananda River, where vegetation cover and open spaces contribute to localized cooling effects.

This spatial contrast between densely built-up areas and vegetated peripheries highlights the strong influence of land cover heterogeneity on thermal distribution. The observed expansion of high-temperature zones over time clearly indicates the intensification and spatial growth of UHI within the municipality, driven primarily by vegetation loss and urban expansion.

## VI. DISCUSSION AND FUTURE IMPLICATIONS

The observed decline in vegetation cover and concurrent expansion of impervious surfaces suggest a continued intensification of Urban Heat Island (UHI) effects in English Bazar Municipality if current land transformation trends

persist. Reduced vegetation limits evapotranspiration and surface shading, while built-up materials increase heat storage and re-radiation, thereby amplifying surface and near-surface temperatures [8, 15]. The strong inverse NDVI–LST relationship identified in this study further indicates that ongoing vegetation loss will likely translate into additional increases in land surface temperature. An intensification of UHI conditions is expected to elevate heat stress levels, particularly during pre-monsoon months when baseline temperatures are already high. Increased exposure to extreme heat has been linked to adverse health outcomes, including heat exhaustion, cardiovascular stress, and higher mortality risk in urban populations [5]. Moreover, rising surface temperatures are associated with increased energy demand for cooling, which may place additional pressure on urban infrastructure and contribute to higher greenhouse gas emissions [10].

Climate projections for South Asia indicate a significant rise in the frequency and intensity of heat extremes under future warming scenarios, with urban areas expected to experience disproportionately higher thermal stress due to localized UHI effects [5]. In regions such as West Bengal, increasing temperature trends combined with rapid urbanization are likely to exacerbate thermal discomfort and reduce overall urban liveability [9]. Therefore, the findings of this study highlight the urgent need for climate-responsive urban planning strategies, including the preservation and enhancement of urban green spaces, implementation of heat mitigation measures, and integration of nature-based solutions. Without such interventions, the combined effects of regional climate change and local land surface transformation are likely to significantly intensify thermal risk in the study area.

## VII. CONCLUSION

This study establishes that vegetation decline is a primary driver of increasing land surface temperature and UHI intensification in English Bazar Municipality. The strong inverse relationship between NDVI and LST highlights the importance of vegetation in regulating urban thermal environments. Sustainable urban planning strategies, including urban greening and preservation of vegetation, are essential to mitigate future thermal risks.

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