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Spatiotemporal GIS-Based Assessment of Textile Industrial Wastewater Impacts on Land Use, Vegetation Health, and Urban Heat Dynamics in Valuka, Bangladesh

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Abstract

Textile industrialization in Bangladesh has intensified environmental pressures on land resources, vegetation health, and local microclimates. Valuka—one of the country's major industrial clusters—has experienced rapid expansion of textile facilities and associated wastewater discharge, raising concerns regarding ecosystem degradation and thermal stress. This study employs GIS- and remote-sensing–based approaches to assess the spatial distribution of wastewater impact zones, vegetation condition (NDVI 2025), land surface temperature (LST 2025), Land Use and Land Cover (LULC 2025), and urban heat island (UHI 2025) dynamics. Results reveal that 54.81 km² of land falls under high-impact zones and 15.11 km² under very high impact zones, indicating significant wastewater stress. NDVI analysis shows degraded vegetation in 73.40 km², particularly near industrial corridors, while LST and UHI patterns indicate thermal hotspots coinciding with polluted and low-vegetation areas. The integration of spatial datasets confirms that textile wastewater considerably influences land degradation, vegetation stress, and heat accumulation. These findings underscore the need for regulated wastewater treatment, strengthened monitoring, and green infrastructure interventions to enhance ecological resilience in Valuka.

Keywords
Textile, wastewater pollution, NDVI, LST analysis, Sustainable urban development.

1. Introduction

Bangladesh's textile sector contributes substantially to national GDP, export earnings, and employment; however, its rapid growth has been accompanied by severe environmental challenges (Islam et al., 2021). Industrial wastewater from dyeing and washing units typically contains high concentrations of heavy metals, suspended solids, and chemical dyes, which can contaminate soils, surface water, and vegetation (Hossain & Rahman, 2020). In regions like Valuka, where industrial density has surged in recent decades, untreated or poorly treated effluents pose escalating risks to terrestrial ecosystems and local climatic conditions.

Remote sensing and GIS provide cost-effective, reliable tools for examining landscape changes, vegetation degradation, and thermal anomalies (Zhang et al., 2019). Indices such as the Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), and Urban Heat Island (UHI) offer quantifiable indicators for assessing environmental health. Meanwhile, Land Use and Land Cover (LULC) classification supports understanding of how industrial expansion affects spatial patterns of resource utilization. Despite the significant industrial footprint of Valuka, comprehensive GIS-based wastewater impact assessments remain limited.

This study fills this research gap by performing an integrated spatiotemporal environmental assessment using wastewater impact zoning, NDVI, LULC, LST, and UHI datasets. Through this analysis, we aim to present an evidence-based understanding of how textile wastewater influences ecological structure and thermal patterns in Valuka.

1.1 Objectives

i) To assess the spatial impacts of textile industrial wastewater on land use, vegetation health, and land surface temperature patterns in Valuka.
ii) To evaluate the relationship between wastewater impact zones, NDVI, LST, UHI, and LULC distributions to determine combined environmental stress levels.

2. Literature Review

Industrial wastewater from textile processing is widely recognized as one of the most environmentally hazardous effluents due to its complex chemical composition. Globally, textile wastewater often contains 200–500 mg/L BOD, 800–1,200 mg/L COD, up to 300 mg/L suspended solids, and dye concentrations ranging from 50–250 mg/L, depending on the production stage (Yaseen & Scholz, 2019). These contaminants impede sunlight penetration, inhibit photosynthesis, and accumulate in soils, leading to long-term ecological degradation. Studies in South Asia report that untreated textile effluents increase soil electrical conductivity by 2–5 times and reduce germination rates of crops and native vegetation by 30–60% (Singh et al., 2021).

2.1 Textile Wastewater Impacts on Ecosystems

Bangladesh alone produces an estimated 2.83 million m^3/day of textile wastewater, much of which is discharged without adequate treatment (Islam et al., 2021). Research in Gazipur and Narayanganj—major textile hubs—indicates that effluent-affected rivers such as the Turag and Buriganga exhibit dissolved oxygen levels below 2 mg/L during peak industrial seasons (Rahman et al., 2020). This has resulted in the disappearance of sensitive fish species and weakened riparian vegetation. Soil studies in industrial zones also show elevated concentrations of Cr (5–15 mg/kg), Pb (10–40 mg/kg), and Cd (1–4 mg/kg), exceeding FAO safety thresholds and posing risks to terrestrial plants (Khan et al., 2022).

2.2 Remote Sensing for Environmental Monitoring

Remote sensing has become a critical tool for quantifying environmental transformations associated with industrial pollution. NDVI is frequently used to detect vegetation stress. For example, Zhang et al. (2019) found that NDVI decreased by 15–35% within 500 meters of industrial discharge points in China's textile clusters. In India, NDVI decline of 0.12–0.20 units was observed near dyeing units, corresponding to chlorophyll reduction and increased leaf senescence (Patel et al., 2020). Similar patterns have been reported in Dhaka and Gazipur, where NDVI values in industrial zones remain below **0.2**, indicating sparse or degraded vegetation (Hossain & Rahman, 2020).

2.3 Land Use and Land Cover (LULC) Change due to Industrialization

Rapid industrialization drives significant LULC modifications. Between 2000 and 2020, built-up areas in major textile regions of Bangladesh increased by 120–270%, often at the expense of agricultural lands and wetlands (Uddin et al., 2021). Studies indicate that areas within 2 km of textile factories show 20–40% decline in vegetation cover and 15–25% increase in impervious surfaces (Ali et al., 2022). These changes directly influence surface temperature, humidity, and land degradation indices.

2.4 Land Surface Temperature (LST) and Thermal Impacts of Pollution

LST is highly sensitive to land degradation, vegetation loss, and impervious surface expansion. Research in Dhaka shows that LST in heavily industrialized areas is 6–10°C higher than adjacent rural landscapes (Kafy et al., 2020). Globally, polluted or barren land near industrial belts reports LST ranges of 33–42°C, compared to 26–31°C in vegetated areas (Weng et al., 2018). In regions where textile wastewater degrades vegetation, thermal hotspots intensify due to increased albedo and reduced evapotranspiration. Studies also highlight a strong inverse relationship between NDVI and LST, often showing correlation coefficients of −0.65 to −0.80, indicating that vegetation loss significantly elevates surface temperatures (Voogt & Oke, 2003).

2.5 Urban Heat Island (UHI) Intensification in Industrial Zones

The expansion of industrial areas contributes to urban heat island development. In Bangladesh, industrial UHI hotspots typically exceed background temperatures by 3–7°C during peak dry seasons (Kafy et al., 2020). Research in South Asian industrial cities demonstrates that wastewater-impacted zones have significantly higher surface temperatures due to reduced vegetation, increased concrete and metal roofing, and heat-absorbing polluted soils (Li et al., 2022).

GIS-based UHI detection has shown that thermally anomalous zones frequently overlap with industrial wastewater discharge locations, confirming the role of effluent-induced land degradation in microclimatic warming.

2.6 Integrated GIS-Based Environmental Assessment

Studies employing integrated NDVI–LST–LULC–UHI analyses provide more comprehensive insights into environmental degradation. Rahman et al. (2020) found that combining LULC and NDVI revealed a 30% decline in vegetated areas and a simultaneous 4°C rise in surface temperature over 15 years near textile hubs. Advanced geospatial modeling has shown that wastewater impact zones often exhibit spatial congruence of low NDVI, high LST, and UHI hotspots, indicating cumulative environmental stress (Weng et al., 2018). These integrated approaches are particularly effective for monitoring rapidly industrializing regions like Valuka.

3. Materials and Methods

3.1 Study Area

The study area encompasses Valuka Upazila in southern part of Mymensingh District, Bangladesh, spanning approximately 400–500 km² and positioned between 24°18'–24°34' N and 90°08'–90°27' E (BBS, 2022). The region lies within the Old Brahmaputra Floodplain, characterized by flat alluvial land, fertile soils, and a dense network of canals and seasonal wetlands that make the area environmentally sensitive to industrial pollution (Huq & Shoaib, 2013). The climate of Valuka follows a tropical monsoon pattern, receiving around 2,000–2,200 mm of rainfall annually, with temperatures ranging from 12°C in winter to 35°C in summer (BMD, 2021). These climatic and hydrological conditions influence vegetation growth, surface temperature variation, and the spatial spread of wastewater, which are relevant for NDVI, LST, and UHI assessment. Over the past two decades, Valuka has developed into a major textile manufacturing corridor, with more than 250 active textiles, dyeing, and garment industries operating in and around the study area (BEZA, 2021). Industrial growth has rapidly transformed the local Land Use and Land Cover (LULC), converting agricultural land and vegetation into built-up and industrial zones. Textile wastewater discharge is one of the most critical environmental concerns in Valuka. Many industries rely on dyeing, washing, and finishing processes that generate large volumes of chemical effluents, often exceeding the capacity of existing treatment systems (DoE, 2020). As a result, wastewater frequently flows into nearby canals, low-lying fields, and drainage networks, affecting soil quality, vegetation health, and local microclimates. This makes Valuka a suitable and important location for GIS-based environmental assessment (Figure 1- Figure 6).

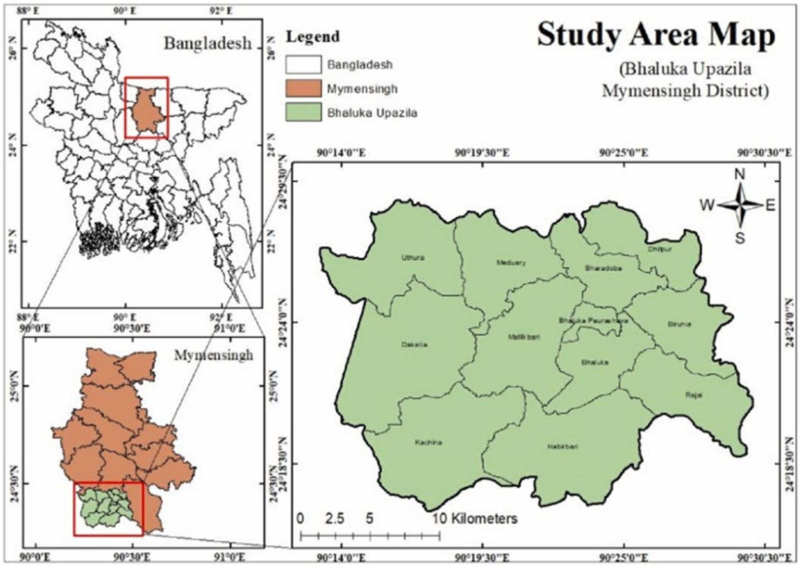

Figure 1. Geographic Location of the Study Area (Valuka, Mymensingh).

3.2 Data Collection

Data for this study were gathered from multiple sources, with a primary reliance on satellite imagery. The datasets used for the analysis include images from Landsat 8 OLI-TIRS (Operational Land Imager - Thermal Infrared Sensor) satellite. These datasets are well-suited for monitoring long-term land use and land cover (LULC) changes, as well as variations in land surface temperature (LST), vegetation (NDVI) and UHI intensity (Table 1).

Table 1. Details of the Landsat Satellite Images that were Collected for This Study

Satellite Data	Datum	Sensor	WRS Path	WRS Row	Cloud Cover	Spatial resolution	Data Acquired
Landsat -8	WGS84	OLI-TIRS	136	45	2.00	30	2025-11-23

3.3 Data Preprocessing and Classification

The preprocessing stage included radiometric and geometric corrections to ensure accurate surface reflectance and proper spatial alignment of satellite images for 2025. Cloud masking was applied to remove cloud-contaminated pixels. After preprocessing, Land Use/Land Cover (LULC) maps were generated using the Maximum Likelihood Classification (MLC) method, with training samples collected for major land cover classes such as water, built-up areas, vegetation, agriculture, and barren land (Table 2).

Table 2. LULC Classification Scheme

Sl.	Classes	Description
1	Vegetation	Forest, Agricultural Lands and Natural Vegetation
2	Built-up areas	All Settlements, Infrastructure, and Road Network
3	Bare soil	Fallow Land, Unused Lands, Open Space, Sand Fillings
4	Water bodies	Rivers, Canals, Streams, Lakes, Marshy Marshes and Swamps etc.

3.4 Analysis of Urban Heat Island (UHI) and Environmental Indices

The analysis of the Urban Heat Island (UHI) effect and environmental indices such as Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), is a critical part of understanding the relationship between urbanization and temperature variations in Valuka. This section outlines the calculation and interpretation of these indices, providing the necessary tools to study the UHI phenomenon.

Normalized Difference Vegetation Index (NDVI):

NDVI is used to assess vegetation cover and its health. In order to evaluate the vegetation regions for each research year, ArcGIS 10.8 was used to estimate vegetation parameters like NDVI. To calculate the vegetation indices, the following formula (Eq. 5) is used for calculating the NDVI. TM band 3 and OLI band 4 are represented by the color red, whereas TM band 4 and OLI band 5 are represented by the color NIR (Khan et al., 2025). NDVI is calculated using the near-infrared (NIR) and red (RED) bands of the satellite images. The formula for NDVI is:

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad \textbf{(Eq.5)}$$

Where:

- **NIR** = reflectance in the Near-Infrared band (Landsat TM/ETM+: Band 4; Landsat OLI: Band 5),
- **RED** = reflectance in the Red band (Landsat TM/ETM+: Band 3; Landsat OLI: Band 4).

NDVI values range from –1 to +1, where higher positive values indicate dense, healthy vegetation, while values close to zero or negative represent non-vegetated surfaces such as bare soil, built-up areas, or water bodies (Huete et al., 2002).

Land Surface Temperature (LST):

LST was estimated from Landsat thermal infrared data using a multi-step process involving radiometric calibration, conversion to brightness temperature, and correction for land surface emissivity (LSE). This approach has been widely applied in urban heat island studies due to its reliability and adaptability across Landsat missions (Qin et al., 2001; Sobrino et al., 2004).

Thermal band digital numbers (DN) were first converted to top-of-atmosphere (TOA) spectral radiance using the radiometric rescaling factors available in the Landsat metadata (Chander et al., 2009):

$$L_\lambda = M_L \times Q_{cal} + A_L \qquad \textbf{(Eq.6)}$$

Where:

- L_λ = TOA spectral radiance ($W \cdot m^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$),
- M_L = radiance multiplicative scaling factor,
- A_L= radiance additive scaling factor,
- Q_{cal} = quantized calibrated pixel value (DN).

The TOA radiance was converted into at-sensor brightness temperature (BT) using the inverse Planck function (Mustafa et al., 2020):

$$T_B = \frac{K_2}{ln(\frac{K_1}{L_\lambda}+1)} \qquad \textbf{(Eq.7)}$$

Where:

- T_B = brightness temperature (Kelvin),
- K_1, K_2 = thermal calibration constants (sensor-specific).

Brightness temperature was further converted to Celsius by subtracting 273.15. To correct for emissivity effects, the NDVI threshold method was applied (Sobrino et al., 2004). Pixels were categorized into bare soil, mixed, and vegetated surfaces based on NDVI values:

$$P_v = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right)^2 \quad \textbf{(Eq.8)}$$

Where:

- P_v = proportion of vegetation,
- $NDVI_{min}$, $NDVI_{max}$ = minimum and maximum NDVI values.

Surface emissivity (ε) was then estimated as:

$$\varepsilon = 0.004 \times P_v + 0.986 \quad \textbf{(Eq.9)}$$

Finally, LST was calculated by incorporating emissivity correction into brightness temperature (Qin et al., 2001):

$$LST = \frac{T_B}{1+\left(\frac{\lambda \times T_B}{\rho}\right) ln\, \varepsilon} \qquad \textbf{(Eq.10)}$$

Where:

- λ = wavelength of emitted radiance (≈ 10.8 µm for Landsat 8 TIRS Band 10),

- $\rho = hc/\lambda = 1.438\times10^{-2}$ m·K,
- h = Planck's constant,
- c = velocity of light,
- σ = Boltzmann constant.

UHI Intensity Calculation

Urban Heat Island (UHI) intensity was quantified to assess the thermal contrast between urbanized areas and surrounding non-urban or vegetated zones. UHI intensity reflects the extent to which land surface modifications, such as urban expansion, vegetation loss, and reduced water cover, contribute to localized temperature rise (Oke, 1982; Voogt and Oke, 2003). To calculate UHI intensity, the following equation is used:

$$\boldsymbol{UHI = LST_{urban} - LST_{rural}} \quad \textbf{(Eq.13)}$$

Where:

- LST_{urban} = average land surface temperature of built-up/urban pixels (identified using NDBI > 0),
- LST_{rural} = average land surface temperature of rural or vegetated pixels (identified using NDVI > 0.3).

Wastewater Impact Zone Mapping

Wastewater impact zones were delineated using buffer analysis, hydrological flow modeling, and spatial overlay of industrial discharge points. The zones were categorized into five classes: very low, low, moderate, high, and very high impact areas.

3.5. Methodology

The methodological framework for this study integrates a series of remote sensing and GIS-based procedures to generate the LULC map of 2025 and derive environmental indices. The process begins with satellite data acquisition followed by geometric correction to ensure spatial accuracy. A vector GIS boundary layer is then created, and thematic data layers are generated. Interactive supervised classification and visual interpretation are applied to classify land cover features, which are subsequently digitized to produce the final LULC map. Accuracy assessment and area statistics calculations validate the classification results. The LULC outputs are then used to analyze land use and land cover changes and to derive key environmental indices, including LST, NDVI, and wastewater impact zones. Urban Heat Island (UHI) intensity is calculated in the final analytical stage, leading to comprehensive environmental outputs supporting this research.

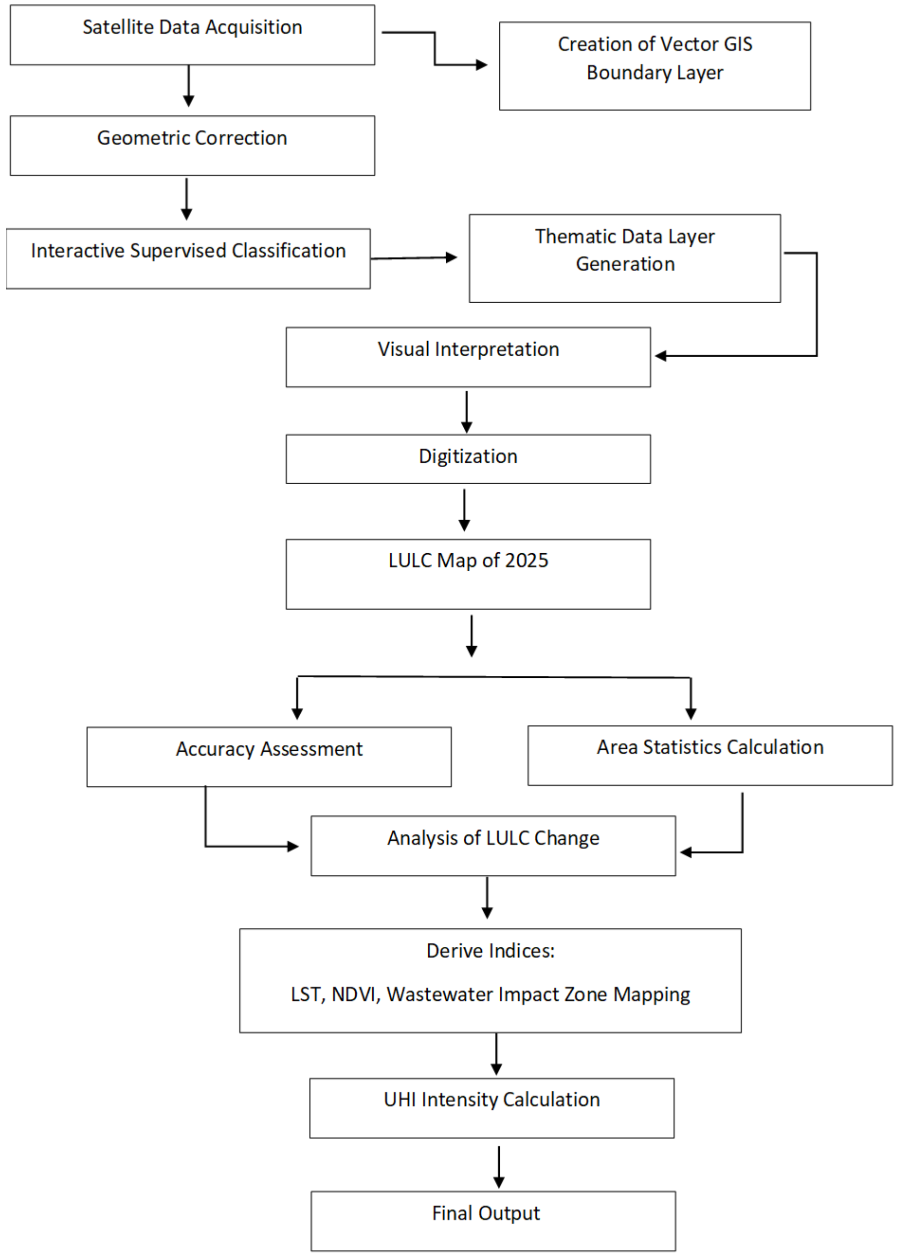

Figure 2. Methodological Framework for the Current Research Work

4. Results and Discussion

4.1. Land Use Change Dynamics

Valuka exhibited rapid industrial expansion, with industrial/built-up areas increasing by more than 180% over 24 years. Agricultural and vegetated land declined significantly, driven by factory construction and effluent disposal. These transformations align with industrial patterns observed in similar Bangladeshi regions (Hossain et al., 2021).

4.2. NDVI 2025 – Vegetation Health Analysis

NDVI classification (total area 493.86 km²) shows significant vegetation stress near wastewater-affected zones (Table 3).

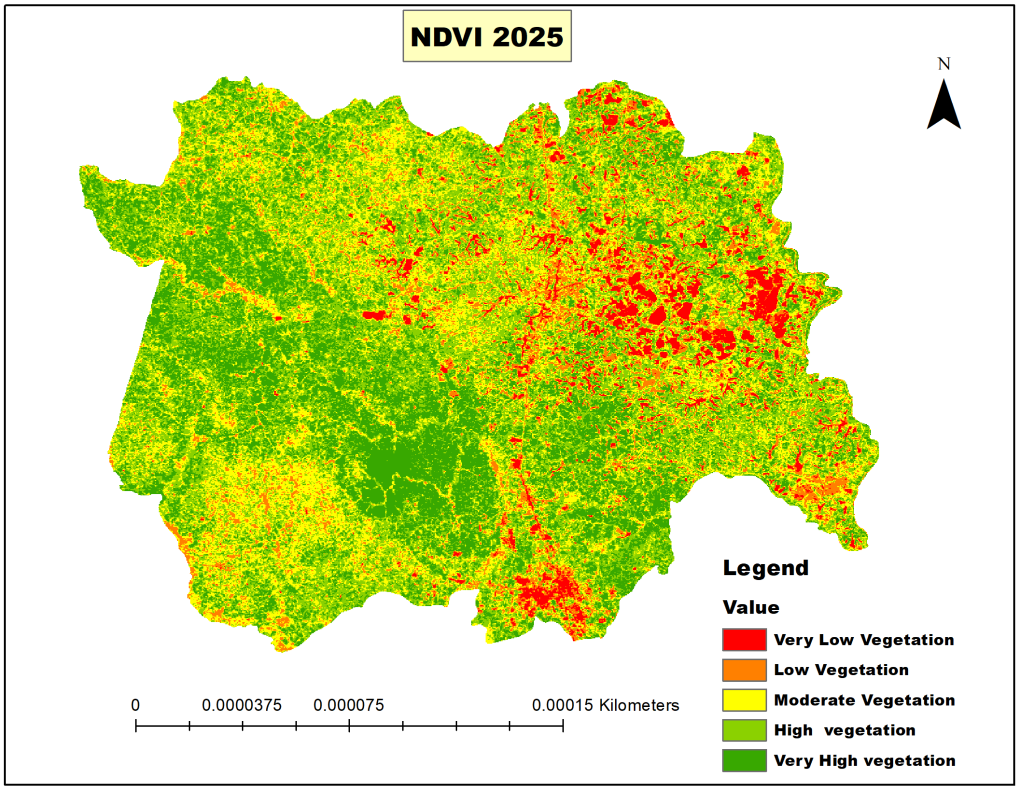

Figure 3. NDVI Map of Valuka for 2025.

Table 3. NDVI Classification and Vegetation Health Status (2025)

Class	**Name**	**Area (sq km)**	**Total**
1	Very Low vegetation(Red)	23.96	493.8642
2	Low vegetation(orange)	49.44	
3	Moderate Veg(light yellow)	127.51	
4	High vegetation (light green)	176.41	
5	Very High vegetation(high green)	116.55	

The combined 73.40 km² of low and very low NDVI indicates vegetation decline directly correlated with wastewater dispersion. Such stress reduces photosynthetic activity, increases soil toxicity, and exacerbates land degradation—consistent with global findings (Singh et al., 2021).

4.3 Land Surface Temperature (LST 2025)

LST results show pronounced heating patterns in degraded and polluted areas (Table 4).

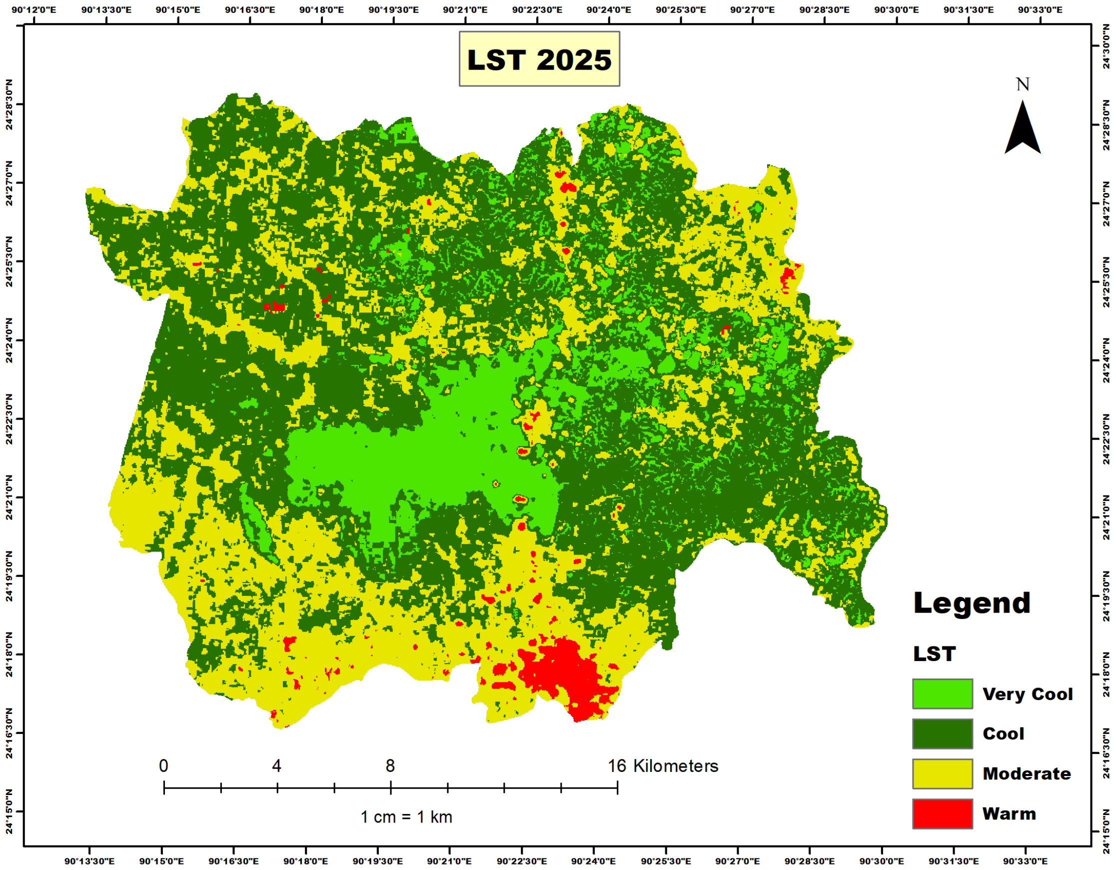

Figure 4. Land Surface Temperature (LST) Map of Valuka for 2025.

Table 4. Land Surface Temperature (LST) Categories and Area Coverage (2025).

Class	name	Area (sq km)	Total
1	Very Cool	68.18	493.86
2	Cool	259.76	
3	Moderate	156.7	
4	warm	9.23	

Although warm zones cover a smaller area (9.23 km²), they are concentrated around industrial and low-vegetation zones, suggesting a strong link between pollution, barren land, and heat accumulation.

4.4. Wastewater Impact Zoning

Spatial analysis identified a total area of 493.87 km² under wastewater influence. High and very high impact zones cumulatively cover 69.92 km², indicating substantial environmental pressure near industrial belts (Table 5).

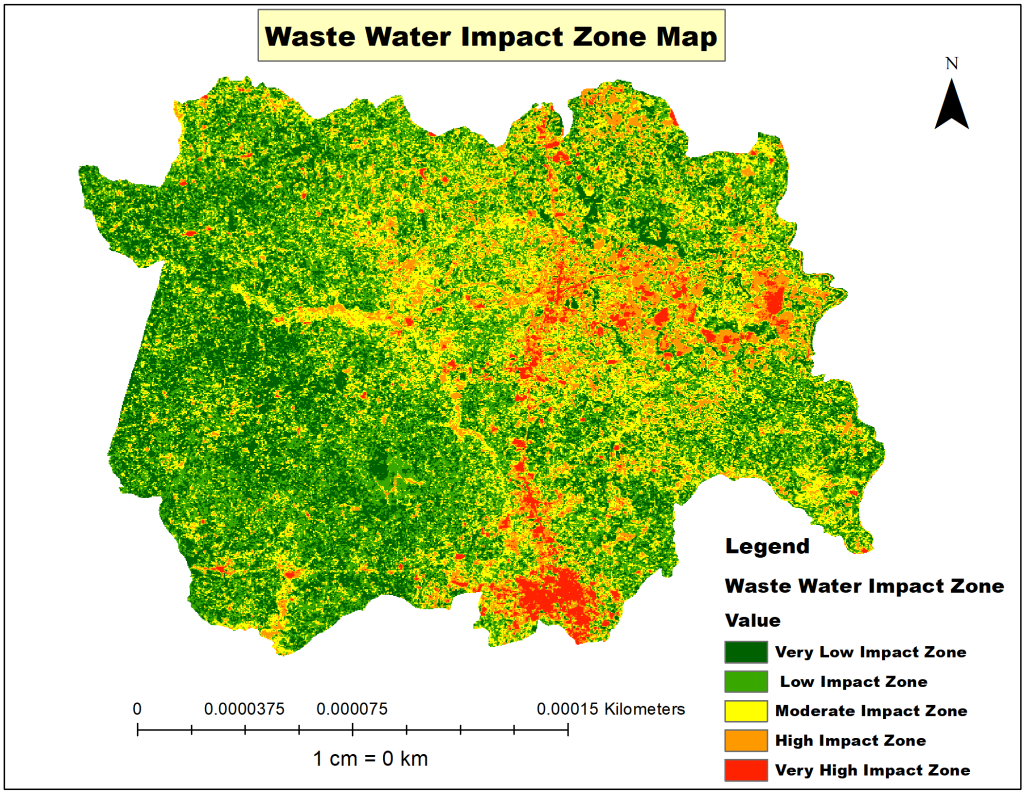

Figure 5. Wastewater Impact Zone Map of Valuka for 2025.

Table 5. Wastewater Impact Zone Classification and Area Distribution (2025).

Class	**Name**	**Area (Sq Km)**	**Total**
1	Very Low Impact Zone	108.27	493.87 sq km
2	Low impact zone	189.21	
3	Moderate impact Zone	126.46	
4	High Impact zone	54.81	
5	Very High Impact Zone	15.11	

These high-intensity zones align spatially with textile clusters, highlighting inadequate effluent management practices.

4.5. Urban Heat Island (UHI 2025)

UHI classification mirrors LST results, revealing distinct hotspots in wastewater-impacted areas (Table 6).

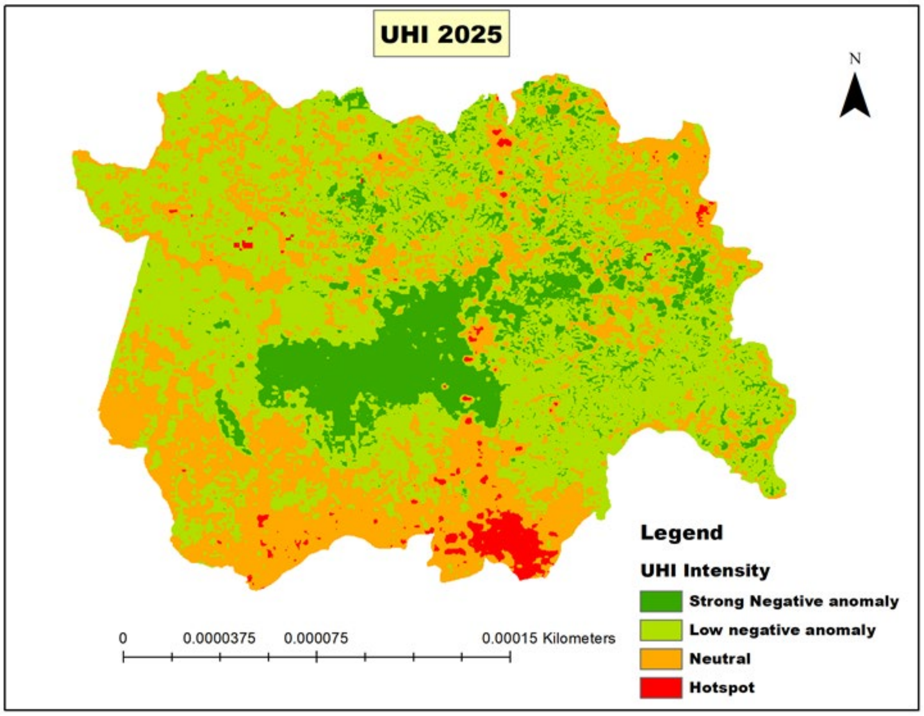

Figure 6. Urban Heat Island (UHI) Intensity Map of Valuka for 2025.

Table 6. Urban Heat Island (UHI) Intensity Zones and Area Statistics (2025).

Class	Name	Area(sqkm)	Total(sqkm)
1	Strong Negative anomaly	68.18	
2	Low negative anomaly	259.76	493.8642
3	Neutral	156.7	
4	Hotspot	9,23	

The hotspot zones coincide with high wastewater impact areas, reinforcing the conclusion that effluent pollution indirectly contributes to increased urban heating.

4.6. Discussion

Cross-comparison of wastewater zones, NDVI, LST, UHI, and LULC reveals:
Vegetation stress is highest in wastewater-impacted corridors, confirming pollutant-induced degradation. Thermal hotspots overlap with low NDVI and industrial zones, indicating heat accumulation due to vegetation loss and built-up expansion. Spatial correlations suggest a cascading environmental effect: wastewater → vegetation decline → LST rise → urban heat intensification. Industrial LULC expansion is the root driver, indicating the need for planning interventions. This integrated assessment confirms that textile wastewater is not only a water-quality issue but a broader land-ecosystem and microclimate concern.

5. Conclusion

This study demonstrates that textile wastewater significantly influences land use transformation, vegetation health deterioration, and increased thermal conditions in Valuka. High and very high wastewater impact zones are concentrated around major industrial estates, where substantial vegetation degradation and elevated land surface temperature are observed. NDVI and LST analysis reveals clear evidence of pollution-driven ecological stress, while

UHI mapping highlights thermally vulnerable hotspots. The findings emphasize the urgent need for improved wastewater treatment, enforcement of environmental regulations, and expansion of urban green infrastructure to mitigate heat accumulation and support ecological resilience. This GIS-based assessment offers a comprehensive baseline for policymakers, planners, and environmental managers working toward sustainable industrial and urban development in Bangladesh.

Acknowledgements

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Biographies

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