Journal of Environmental Science, Health & Sustainability, 2026, 2(2), 147–159
https://journals.enviromindsolutions.com/jeshs
eISSN: 3067-946X

Article

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Comparative analysis of normalized difference index for assessing urbanization, forest degradation, and water body changes: A case study of Sylhet and Gazipur districts, Bangladesh

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How to cite

Banik, T., Seddique, A.A., 2026. Comparative analysis of normalized difference index for assessing urbanization, forest degradation, and water body changes: A case study of Sylhet and Gazipur districts, Bangladesh. Journal of Environmental Science, Health & Sustainability, 2(2), 147–159.
https://doi.org/10.63697/jeshs.2026.10078

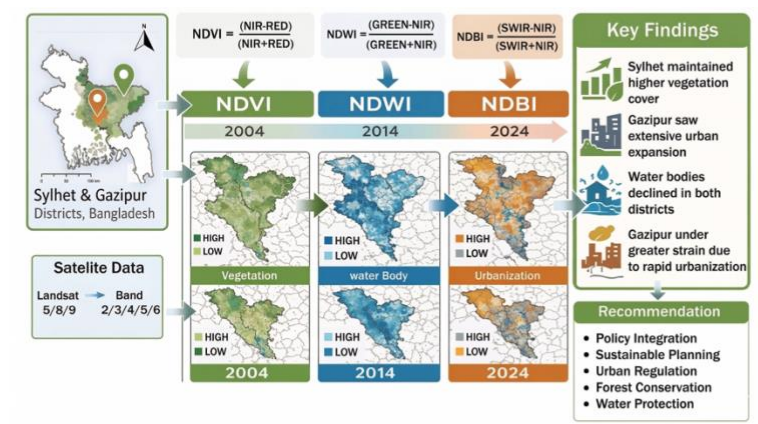
Article info

Received: 29 December 2025
Revised: 13 March 2026
Accepted: 20 March 2026

Keywords

Urbanization
Forest degradation
Water body changes
Land cover changes
Bangladesh

Graphical abstract



Highlights

- *Environmental changes from 2004 to 2024, as measured by GIS and remote sensing indices.*
- *Declining vegetation in Gazipur and consistent greenery in Sylhet.*
- *Rapid urban expansion in Gazipur compared to Sylhet.*
- *Progressive decline of surface water bodies.*
- *Accelerating land transformation in Gazipur due to industrial and urban pressure.*

Abstract

Bangladesh has experienced rapid urbanization in recent years, leading to significant ecological changes. This study examines land cover variations in Sylhet and Gazipur districts, with an emphasis on vegetation, urbanization, and water bodies, to assess the environmental impacts of urban development, including decreased vegetation. Remote sensing data from 2004 to 2024 were analyzed using Geographic Information System (GIS) to identify long-term changes through the Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), and Normalized Difference Water Index (NDWI). The seasonal variations were highlighted through separate examinations of the data. The outcomes revealed different trajectories for the two districts. NDVI analysis indicates contrasting vegetation dynamics between the two districts. In Sylhet, winter NDVI declined by 9.05% over the 2004–2024 period, while summer NDVI increased by 11.52%, reflecting seasonal growth variability but ecological sensitivity. In contrast, Gazipur recorded modest vegetation gains (5.25% in winter and 0.32% in summer), suggesting limited recovery amid developmental pressures. NDBI trends reveal substantially stronger urban expansion in Gazipur, where built-up intensity increased by 59.7% in winter and 16.33% in summer, compared to seasonal

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Handling Editor: Dr. B. Nath with assistance from Dr. P. D. Roy.

declines in Sylhet (10.21% in winter and 31.67% in summer). Water body dynamics further highlight divergence: Sylhet experienced marked NDWI reductions (41.39% in winter and 21.43% in summer), whereas Gazipur showed seasonal instability, with a 12.31% winter increase but a sharp 34.3% summer decline. Overall, Sylhet appears less urbanized but hydrologically vulnerable, while Gazipur demonstrates pronounced urban-driven ecological strain. These findings demonstrate the urgent need for sustainable planning through planned reforestation, green space conservation, and effective water resource management, among other measures, to minimize ecological degradation.

1 Introduction

Environmental degradation and rapid urbanization have become global concerns, particularly in rapidly growing countries such as Bangladesh. Over 55% of people currently reside in cities, and it is predicted to increase to 68% by 2050 (United Nations, 2020). Rapid urbanization has threatened the stability of ecological systems and caused a range of environmental issues, including deforestation, reduced biodiversity, water scarcity, and increased pollution (Seto et al., 2012). These changes have affected local temperatures, disrupted hydrological cycles, generated extensive ecological reflection, and reduced the ecosystem's ability to adapt to climate change (Foley et al., 2005). Remote sensing technologies make it easier to monitor changes in vegetation, aquatic systems, and urban areas over time by providing accurate, comprehensive land cover databases derived from satellite and aerial imagery (Pettorelli et al., 2005). The use of spectral indices such as Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), and Normalized Difference Water Index (NDWI) is one of the best ways to monitor these changes (Tucker, 1979; McFeeters, 1996; Zha et al., 2003).

Khine et al. (2018) used Google Earth Engine (GEE) to analyze variations in NDWI, NDVI, and NDBI indices in Mawlamyine city. They found a significant relationship between changes in vegetation health, water resources, and urban expansion. Alademomi et al. (2022) study shows that urban expansion is associated with higher temperatures and reduced vegetation, as indicated by links among Land Surface Temperature (LST), NDVI, NDBI, and land cover changes in Lagos, Nigeria. Zheng et al. (2021) highlight the significance of NPP-VIIRS evening light data for sustainable urban planning by proposing an integrated approach for monitoring urban areas that combines NDVI, NDWI, and NDBI indices. Ukhnaa et al. (2019) propose an advanced technique for defining urban built-up areas using thematic index-derived bands, improving accuracy, tracking urban sprawl, and promoting sustainable development. Aslan and Koc-San's (2021) underline the effectiveness of forest cover indices (NDVI, NDWI, and NDBI) in detecting surface urban heat islands (UHI) using Landsat imagery, emphasizing the need for timely data to guide urban planning strategies. Xu (2008) introduces a satellite image-based index for identifying built-up land, enhancing remote sensing efficiency, and implications for urban planning and land management. Fatima et al. (2022) conducted an environmental resource monitoring study in Sindh, Pakistan, using NDVI and NDWI, revealing significant trends in land use transformation, water scarcity, and vegetation decline.

Sharma and Arote (2022) found significant correlations among NDVI, LST, NDWI, SMI (Soil Moisture Index), and NDBI, highlighting the effects of increasing urbanization, changes in surface area, and shifts in vegetation health on temperature fluctuations in Kamrup Metropolitan District, India. Chandramohan et al. (2024) found that land degradation patterns, particularly in areas with resource overexploitation and land use changes, are influenced by NDVI, NDWI, SMI, and Leaf Area Index (LAI), underscoring the need for sustainable land management. Guha and Govil (2022) observe a significant relationship between elevated LST and higher NDBI values in UHI in Hyderabad, underscoring the need for geospatial modeling for climate resilience. Al-Issawi and Al-Falahi (2022) use spectral indices such as NDVI, NDBI, NDWI, and MSAVI (Modified Soil Adjusted Vegetation Index) to assess agricultural land use in the Karma district, identifying diverse categories and providing insights for sustainable agricultural land-use assessment through remote sensing methods. Bhatti and Tripathi (2014) use Landsat 8 OLI imagery and NDVI and NDBI techniques to accurately assess urbanization trends, advancing urban remote sensing for sustainable development. Mathew et al. (2022) use NDVI and NDBI indices to analyze diurnal LST variations in Ahmedabad, India, revealing distinct patterns linked to land cover types, which are crucial for effective urban planning and climate resilience. Sharma and Joshi (2016) use NDVI, NDWI, and NDBI to assess the environmental impact of rapid urbanization, emphasizing the importance of remote sensing data for sustainable planning. Guha et al. (2019) study reveals significant seasonal variations in land surface temperature using NDVI, NDWI, NDBI, and NMDI (Normalized Multiband Drought Index), highlighting the need to understand these dynamics for efficient urban growth and environmental conservation. Das et al. (2023) assessed remotely sensed data for drought surveillance in the northwestern region of Bangladesh, focusing on NDVI and NDWI to understand drought impacts.

Bangladesh, a developing nation with one of the world's most densely populated areas, is rapidly urbanizing. The nation's urban population has increased in large cities such as Dhaka, Chittagong, and Gazipur over the last few decades (Roy et al., 2020). Over 37% of Bangladeshis already reside in urban areas, and this number is expected to rise dramatically over the coming decades. Roy et al. (2020) found a link between rising surface temperatures and urbanization in Bangladesh's Chattogram Metropolitan Area, highlighting the importance of environmentally friendly urban design. Faisal et al. (2019) study in Modhumoti Model Town, Bangladesh, used remote sensing methodologies to assess land degradation and wetland loss, highlighting the importance of monitoring wetland ecosystems for environmentally responsible urban planning and management. Imran et al. (2021) reported an increase in LST associated with urban growth, as observed in a study conducted in Dhaka, Bangladesh, using NDVI, LST, and NDBI metrics. While several studies have looked at the relationship between LST and urban growth in Bangladesh (Roy et al., 2020; Imran et al., 2021; Abir and Saha, 2021), most of these studies are restricted to single-city analysis and mostly concentrate on temperature-urbanization interactions.

Gazipur is an industrial hub near Dhaka, particularly in the textile and apparel sectors. Its natural landscapes have changed due to urbanization and residential development, leading to ecological deterioration. On the other hand, Sylhet is well known for its marshes, lakes, and rivers, verdant hills, and abundant wildlife. It was historically less urbanized than Gazipur but has seen comparable urban expansion in recent years. This study compares land cover changes in both Sylhet and Gazipur districts to provide a comprehensive understanding of environmental changes driven by urbanization, deforestation, and declines in water bodies. To ensure data reliability, this study utilizes satellite imagery from Landsat 5, 8 & 9 spanning 2004, 2014, and 2024 to provide high-resolution, multispectral data suitable for analyzing land cover changes over time. The primary goals of this study are to quantify forest degradation using NDVI, with an emphasis on seasonal and temporal variations; assess urban expansion and changes in land cover in both districts using NDBI; assess changes in water bodies using NDWI, looking at the consequences of urbanization, climate fluctuation and compare how the two region's urbanization, deforestation and water body depletion have affected the ecosystem.

2 Methods and materials

2.1 Study area

Sylhet and Gazipur are two districts of Bangladesh with distinct physical and environmental features (**Fig. 1**). Sylhet is well-known for its lush hills, thick woods and proximity to haor-wetlands. Its vast, lowlands and rolling hills are essential for comprehending ecological shifts. Gazipur, located to the north of Dhaka is known for its rapid industrial growth and urbanization, which has an impact on its agricultural and wooded areas. The two regions geographical distinctions offer a through comparison for analyzing changes in land use.

2.2 Data

Landsat 9 OLI 2 (Operational Land Imager), Landsat 8 OLI, and Landsat 5 TM (Thematic Mapper) imagery of the USGS Earth Explorer comprise the primary satellite data (**Table 1**). Twelve Landsat imageries were selected for this study (six for Sylhet and six for Gazipur), spanning 2004 to 2024. Criteria for cloud-free, shade-free imagery were used to select the imagery to ensure the accuracy of the categorization. Landsat data with a spatial resolution of 30 meters, the World Geodetic System (WGS84) datum, and a popular reference system for geographic data are used for this work. WRS Row for both districts is 43, and the WRS Path for Sylhet and Gazipur are 136 and 137, respectively. In Bangladesh, the winter season lasts from December to February, and the summer season begins in April and lasts

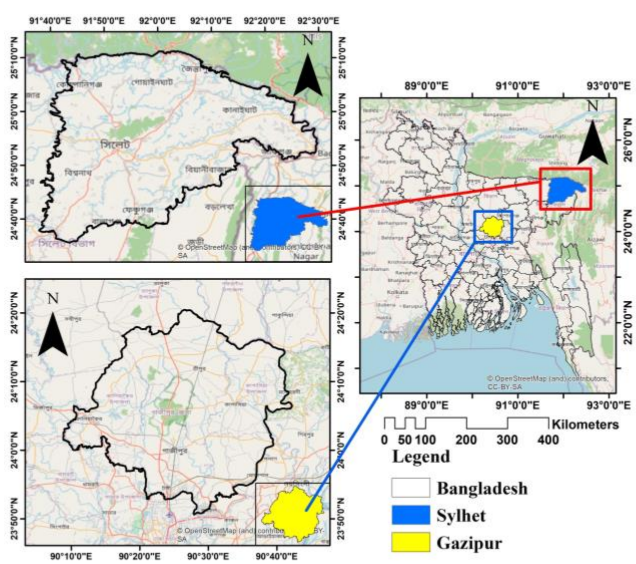

Figure 1. *Location of the study region of Sylhet and Gazipur districts, Bangladesh.*

Table 1. *Details of the Landsat satellite images for land cover maps for the Sylhet and Gazipur districts of Bangladesh used in this study.*

Sylhet				Gazipur			
Satellite	***Cloud cover***	***Bands***	***Date***	***Satellite***	***Cloud cover***	***Bands***	***Date***
Landsat -5	0.0	2, 3, 4, & 5	2004-02-08	Landsat -5	0.0	2, 3, 4, & 5	2003-12-13
Landsat -5	4.0	2, 3, 4, & 5	2004-04-28	Landsat -5	0.0	2, 3, 4, & 5	2004-04-02
Landsat -8	0.02	3, 4, 5, & 6	2014-02-19	Landsat -8	3.56	3, 4, 5, & 6	2014-01-25
Landsat -8	0.20	3, 4, 5, & 6	2014-04-24	Landsat -8	0.34	3, 4, 5, & 6	2014-03-30
Landsat -8	0.46	3, 4, 5, & 6	2024-01-30	Landsat -8	2.48	3, 4, 5, & 6	2023-12-20
Landsat -9	10.91	3, 4, 5, & 6	2024-05-13	Landsat -9	12.35	3, 4, 5, & 6	2024-04-26

until June or July. Gloomy skies characterize the monsoon season, whereas the winter, pre-summer, and summer seasons are usually cloudless. Thus, winter-season and pre-summer or summer-season photos were the primary sources of data.

To minimize short-term fluctuations and provide a clear assessment of long-term environmental shifts, the years 2004, 2014, and 2024 were selected to represent three decadal benchmark periods spanning 20 years. In regional land use change studies, a 10-year interval is frequently employed to capture important structural changes. Additionally, the availability of cloud-free and seasonally equivalent Landsat data for both winter and summer periods limited the selection. Due to the lack of cloud-free satellite images for January-February 2004 and 2024 for the Gazipur region, imagery from December 2003 and December 2023 was used to represent winter-season conditions.

2.3 Data processing and analysis

Landsat images were analyzed in ArcGIS 10.8, and the satellite-derived data were subjected to a series of preprocessing steps, including atmospheric correction using the Dark Object Subtraction (DOS) technique, geometric correction, and radiometric normalization. NDVI, NDWI, and NDBI metrics were derived from their associated spectral bands (**Fig. 2**).

2.3.1 Normalized difference vegetation index (NDVI)

The NDVI computation involves preprocessing Landsat imagery to mitigate atmospheric disturbances, such as haze and cloud cover, using ArcGIS 10.8. The red band (specifically band 4 for Landsat 9 OLI 2 / 8 OLI and band 3 for Landsat 5 TM) and the near-infrared band (band 5 for Landsat 9 OLI 2 / 8 OLI and band 4 for Landsat 5 TM) are selected for NDVI computation. The imagery is then processed to derive the NDVI values (Essaadia et al., 2022).

Trends in vegetation cover, such as deforestation or reforestation, can be identified by comparing NDVI readings over multiple time periods. NDVI values range from -1 to +1. High NDVI values (>0.6) indicate dense, healthy vegetation, such as crops and forests. Sparse vegetation or grassland is indicated by a medium NDVI values (0.2 to 0.6). Bare soil or populated areas are indicated by a low NDVI values (0 to 0.2). Cloud cover or water bodies are indicated by a negative NDVI (Tucker, 1979).

2.3.2 Normalized difference built-up index (NDBI)

NDBI measure is calculated using the near-infrared band (band 5 for Landsat 9 OLI 2 / 8 OLI and band 4 for Landsat 5 TM) and short-wave infrared band (band 6 for Landsat 9 OLI 2 / 8 OLI and band 5 for Landsat 5 TM).

Urban expansion can be tracked and its effects on surrounding areas evaluated by comparing NDBI values across years (which range from -1 to +1). Positive NDBI (>0) indicates the existence of built-up regions; higher values

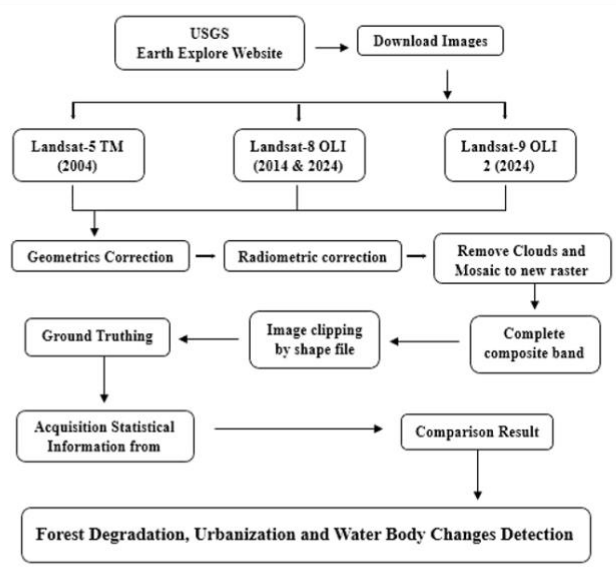

Figure 2. *The overall methodological framework of this study.*

indicate denser urbanization, while negative NDBI (<0) corresponds to vegetation or natural land cover (Zha et al., 2003; Xu, 2008).

2.3.3 Normalized difference water index (NDWI)

NDWI is calculated using the green band (band 3 for Landsat 9 OLI 2 / 8 OLI and band 2 for Landsat 5 TM) and near-infrared band (band 5 for Landsat 9 OLI 2 / 8 OLI and band 4 for Landsat 5 TM) are used for the computation of NDWI.

Water resource management depends on the ability to identify changes in water bodies, such as seasonal variations or long-term water loss, by analyzing NDWI over time. NDWI values range from -1 to +1. Water bodies, including lakes, rivers, and wetlands, are indicated by positive NDWI (>0), and the negative NDWI suggests urban or arid regions (McFeeters, 1996).

2.3.4 Validation and accuracy assessment

To ensure classification reliability, threshold for NDVI, NDBI, and NDWI values were derived from the literature (Tucker, 1979; McFeeters, 1996; Zha et al., 2003). The overall applicability of threshold values for NDVI, NDBI, and NDWI under regional conditions was assessed by examining histogram distributions and spectral separability within the study areas, even though these ranges were taken from the literature. To ensure proper separation between vegetation, built-up areas, and water bodies in the study area, the chosen threshold values were visually evaluated against high-resolution imagery. Representative locations were validated utilizing high-resolution historical imagery from Google Earth Pro (2004, 2014, and 2024) to ascertain vegetation cover, urban expansion, and water body distribution. Furthermore, spatial consistency among indices (e.g., the inverse relationship between NDVI and NDBI in urbanized areas) was examined to enhance internal validity. Despite the absence of field-based ground truth data from previous years, these methodologies provide reasonable assurance of the reliability of the findings.

3 Results

3.1 NDVI for the winter season

3.1.1 In the Sylhet area

The maps of Sylhet during winter over two decades show a fluctuating trend in vegetation health. From 2004 to 2014, peak values increased from 0.485 to 0.518, indicating improved biomass or agricultural output. However, by 2024, a significant decline to 0.441 suggests environmental stress, likely driven by urban expansion, land-use changes, or shifting climatic conditions (**Fig. 3a-c**).

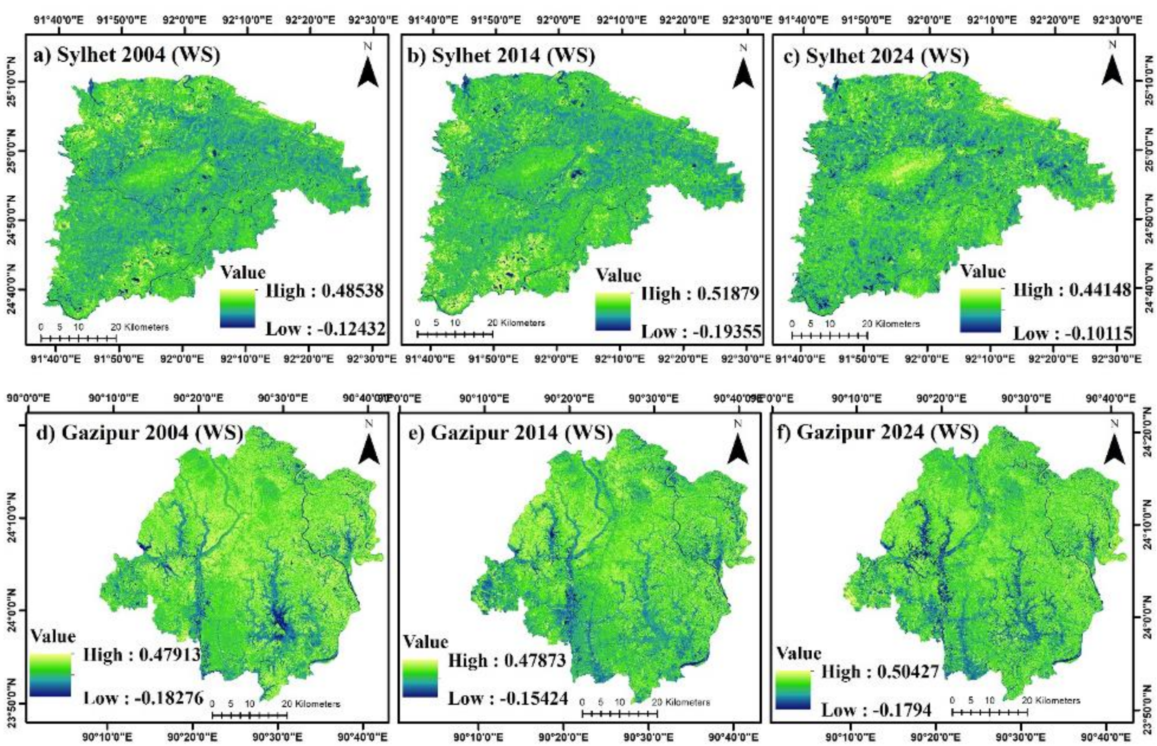

Figure 3. *Spatiotemporal variation of NDVI values of Sylhet (a, b, & c) and Gazipur (d, e, & f) districts throughout the winter season (WS) for the years of 2004, 2014, and 2024, respectively.*

3.1.2 In the Gazipur area

The winter season maps for Gazipur indicate initial stability in NDVI values, with a slight decrease from 0.479 to 0.478 between 2004 and 2014. However, by 2024, the maximum value rose to 0.504, indicating a shift in land cover characteristics. The 2024 map reveals a more homogeneous distribution of high values in the center, contrasting with previous years' dispersed patterns, possibly due to changes in agricultural density or seasonal drying of water bodies (**Fig. 3d-f**).

3.2 NDVI for the summer season

3.2.1 In the Sylhet area

The data shows a brief decrease followed by an increase in peak values. The highest value was 0.491 in 2004, but by 2014 it had decreased to 0.440, indicating 10 years of poorer vegetation health or greater summertime environmental stress. However, by 2024, the region exhibits a sharp intensification or rebound, with the peak value reaching 0.547 (**Fig. 4a-c**).

3.2.2 In the Gazipur area

In Gazipur, a sudden rise in environmental intensity followed by a regression toward baseline levels characterizes the data's nonlinear pattern. The peak value was 0.479 in 2004 and increased to 0.523 by 2014, indicating 10 years of substantial biomass growth or increased summertime land use. However, by 2024, the NDVI values had fallen to 0.480, approaching the levels of twenty years earlier (**Fig. 4d-f**).

3.3 NDBI for winter season

3.3.1 In the Sylhet area

Over the 20-year study period, land development and urban density variations in Sylhet highlight critical trends for urban planning and environmental management. The NDBI value peaked in 2004 at 0.214 and reached its maximum value in 2014 at 0.228, indicating ten years of active infrastructure expansion and construction. Nevertheless, the highest NDBI value fell to 0.192 by 2024 (**Fig. 5a-c**).

3.3.2 In the Gazipur area

The maps of Gazipur's NDBI reveal a significant increase in urban areas over 20 years, with values rising from 0.218 in 2004 to 0.348 in 2024. This urban network expanded from isolated patches in 2004 to a more extensive interconnected area by 2024, underscoring Gazipur's rapid development into a dense industrial and residential hub (**Fig. 5d-f**).

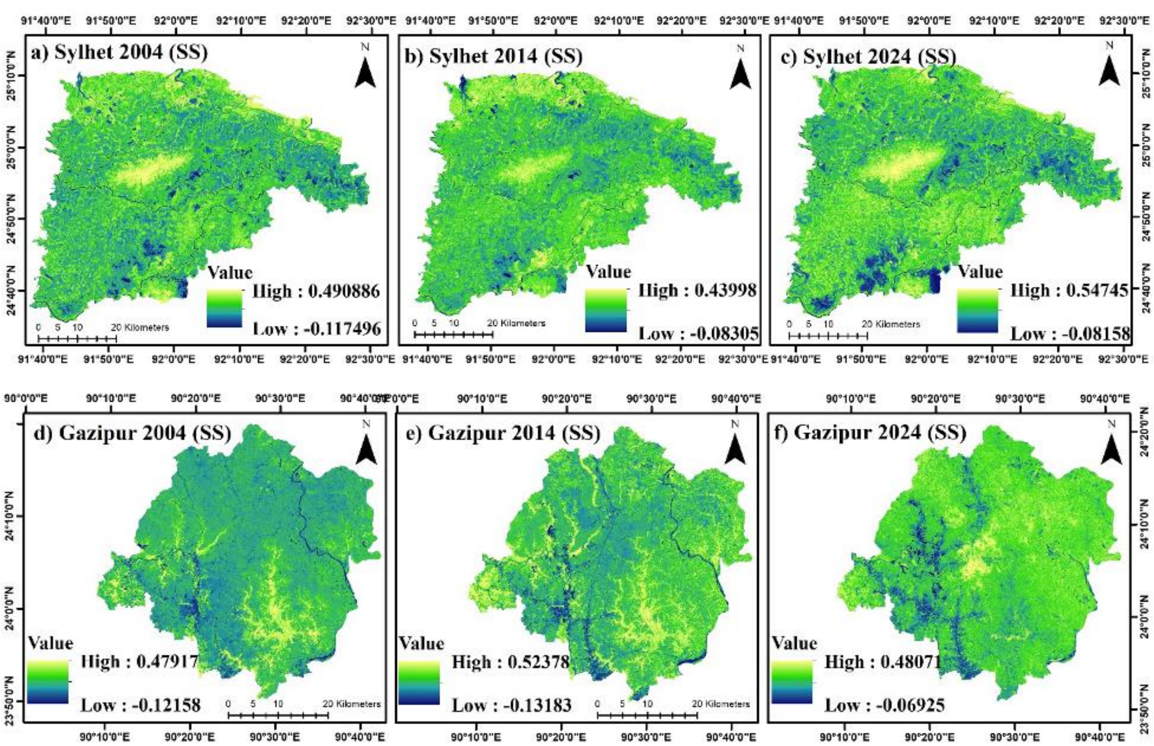

Figure 4. *Spatiotemporal distribution of NDVI values across Sylhet (a, b, & c) and Gazipur (d, e, & f) districts during the summer season (SS) for the years of 2004, 2014, and 2024, respectively.*

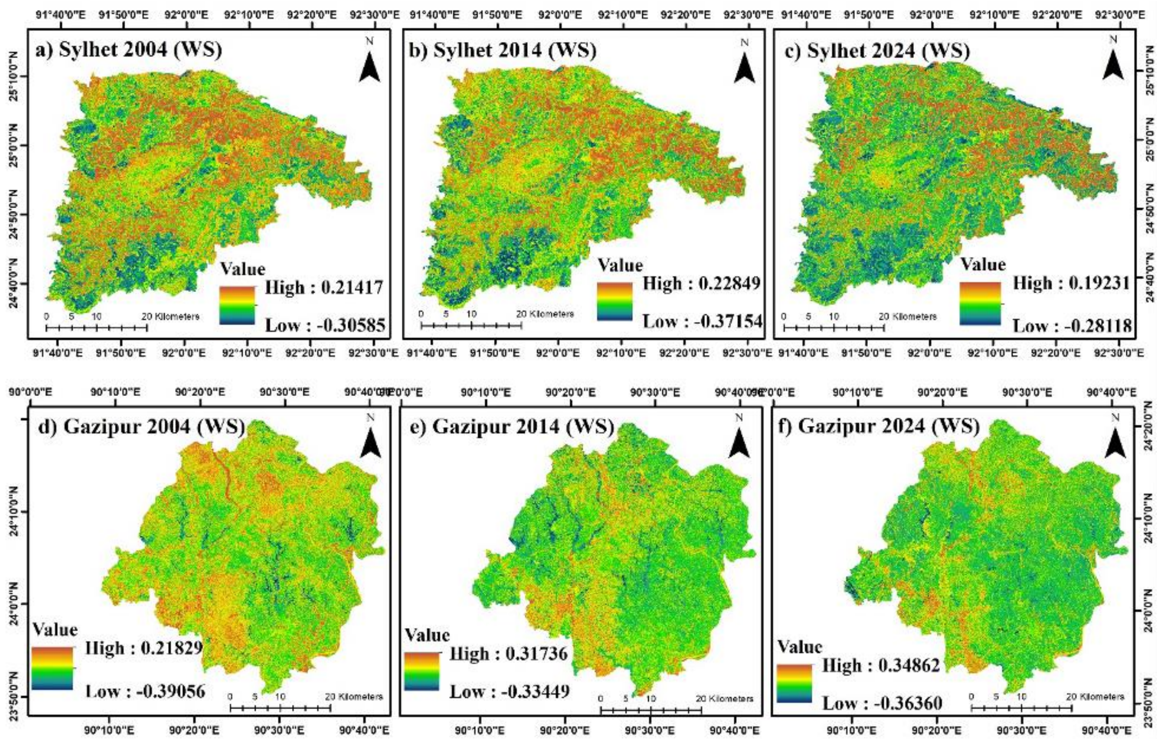

Figure 5. *Spatiotemporal variation of NDBI values of Sylhet (a, b, & c) and Gazipur (d, e, & f) districts during the winter season (WS) for the years of 2004, 2014, and 2024, respectively.*

3.4 NDBI for summer season

3.4.1 In the Sylhet area

A distinct pattern of early urban development followed by mild stabilization is evident in Sylhet's NDBI during summer. The NDBI values peaked at 0.242 in 2004 and increased sharply to 0.303 by 2014, indicating rapid summer-time built-up growth. The value slightly decreased to 0.283 by 2024 but remained substantially higher than the 2004 value (**Fig. 6a-c**).

3.4.2 In the Gazipur area

Over a 20-year study, Gazipur experienced a consistent rise in impervious surfaces, which correlated with rapid urbanization. The NDBI increased from 0.257 in 2004 to 0.298 in 2014, peaking at 0.299 in 2024, indicating a high built-up density. The transformation from fragmented high-intensity zones in 2004 to a more cohesive urban core by 2024 illustrates Gazipur's development into a densely populated industrial and residential area (**Fig. 6d-f**).

3.5 NDWI for winter season

3.5.1 In the Sylhet area

Surface water and soil moisture levels have changed significantly in Sylhet during winter over the past 20 years. In 2004, the top NDWI value was 0.150; by 2014, it was 0.190, demonstrating improved water retention. However, by 2024, it had fallen to the lowest-ever recorded level of 0.088. This declining trend is consistent with a visible decrease in high-moisture content between 2014 and 2024, which may indicate hydrological changes in the area driven by climate change or the loss of water bodies (**Fig. 7a-c**).

3.5.2 In the Gazipur area

Over the past 20 years, surface water and soil moisture levels in Gazipur have fluctuated, with an overall increase observed in NDWI values during the winter season. The peak NDWI value was 0.195 in 2004, falling to 0.151 by 2014, then rebounding to 0.218 by 2024. The data indicate that "high-moisture" zones, which diminished in 2014, regained intensity and expanded in central and western regions by 2024 (**Fig. 7d-f**).

3.6 NDWI for summer season

3.6.1 In the Sylhet area

The NDWI analysis for Sylhet over the past ten years reveals a considerable seasonal drying or loss of open water bodies, with peak surface moisture falling from 0.128 in 2004 to a low of 0.073 in 2014. A partial recovery to 0.100 is observed by 2024. The mapping shows a change from large, high-

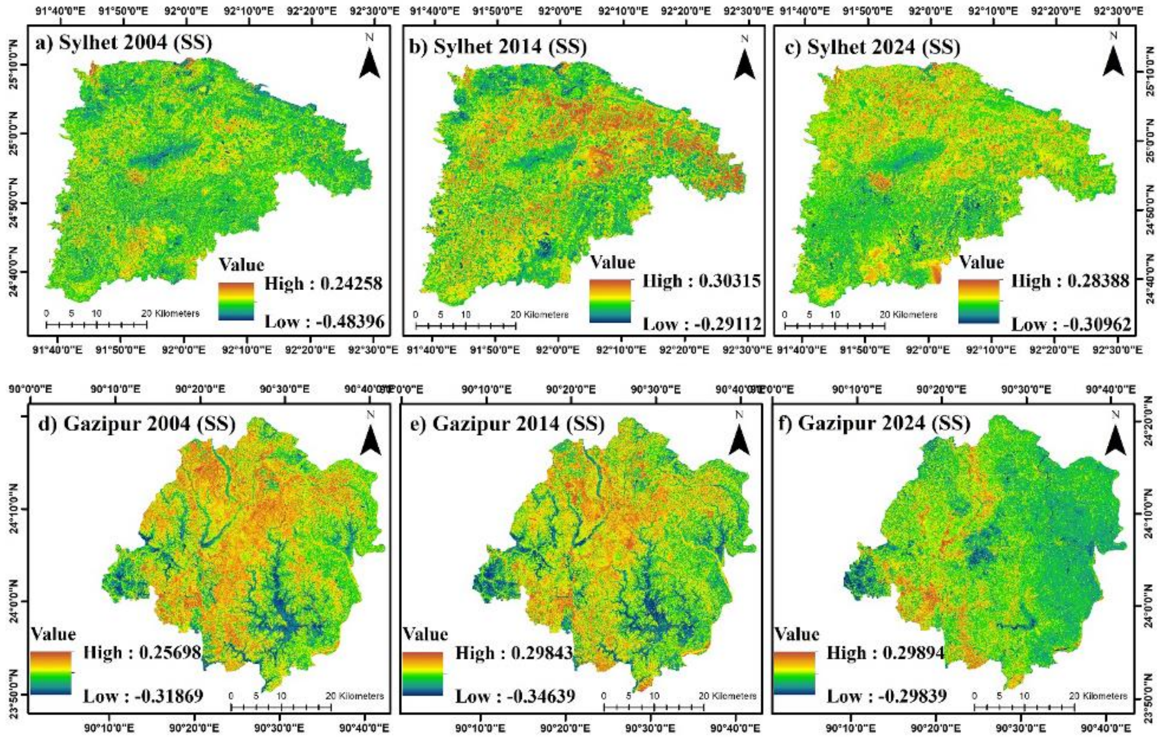

Figure 6. *Spatiotemporal distribution of NDBI values for Sylhet (a, b, & c) and Gazipur (d, e, & f) districts during the summer season (SS) for the years of 2004, 2014, and 2024, respectively.*

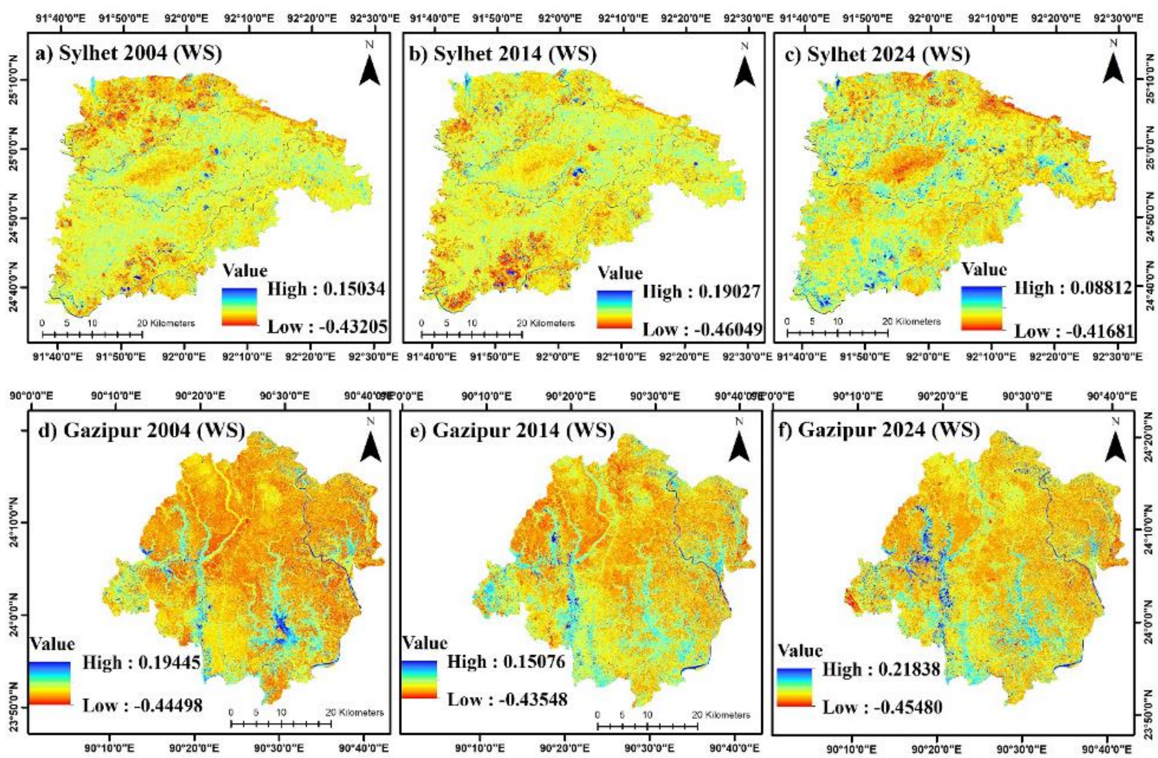

Figure 7. *Spatiotemporal variation of NDWI values for Sylhet (a, b, & c) and Gazipur (d, e, & f) districts during the winter season (WS) for the years 2004, 2014, and 2024, respectively.*

moisture zones in 2004 to a dispersed, lower-intensity pattern in 2014 and 2024. Although summer water availability has not been restored to levels seen in the early 2000s, this pattern indicates some hydrological resilience.

This is probably because of long-term changes in drainage or climate (**Fig. 8a-c**).

3.6.2 In the Gazipur area

The NDWI analysis for Gazipur reveals moderate stability in water levels from 2004 to 2014, with a maximum value of 0.128. However, by 2024, this value sharply declined to 0.079, marking the lowest in two decades. Maps show a transition from densely moist areas in 2014 to dispersed lighter zones in 2024, indicating increased summer dryness. This trend coincides with rising NDBI values, suggesting a significant loss of natural water bodies and wetlands from rapid development (**Fig. 8d-f**).

4. Discussion

4.1 Evaluation of land surface indices and area classification

In Sylhet, over the span of two decades, i.e., between 2004 and 2024, the NDVI values during the winter season decreased by 9.05%, suggesting a decrease in vegetation density or vitality. Conversely, it has risen by 11.52% during the summer season, indicating an increase in vegetation density and health. NDBI values for the winter have also fallen by 10.21% pointing to an increase in built-up areas or urbanization. It dropped by 31.67% in summer, indicating a huge increase in urban development. A 41.39% decrease in NDWI in winter indicated a notable reduction in water availability or moisture content. Similarly, its 21.43% drop in summer suggested a consistent decline in water availability.

In Gazipur over the same twenty-year period, the NDVI values in winter has increased by 5.25%, showing a slight increase in vegetation density during summer. It has risen by 0.32% from 2004 to 2024, indicating a very slight improvement. The NDBI values in winter has increased by 59.7%, reflecting significant urban expansion and development of built-up areas, and in summer, it has increased by 16.33%, which indicates urban growth. The NDWI in winter has risen by 12.31%, indicating an improvement in water presence or moisture content. In contrast, in summer, it has decreased by 34.3% indicating a huge reduction in water presence or moisture content.

4.2 Implications for environmental health and urban sustainability

A structural shift toward more impermeable and development-dominated landscapes is reflected in the observed growth of built-up areas in Sylhet and Gazipur. This change significantly impacts environmental sustainability and public health. The reduction in vegetative cover exacerbates UHI effects, increasing heat-related stress and respiratory hazards (Salam et al., 2024). Highlighting these health risks

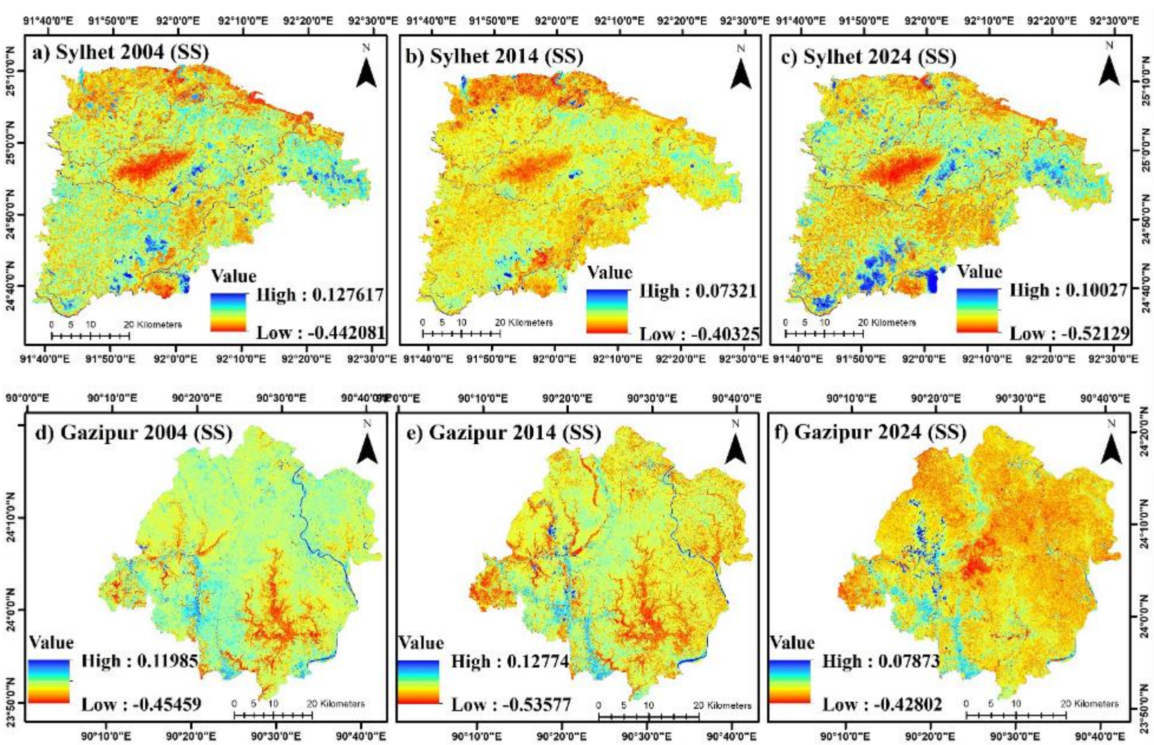

Figure 8. *Spatiotemporal variation of NDWI values for Sylhet (a, b, & c) and Gazipur (d, e, & f) districts during the summer season (SS) for the years of 2004, 2014, and 2024, respectively.*

can motivate the stakeholders to prioritize environmentally responsive urban planning and health considerations. Concurrently, the growth of impermeable surfaces alters natural hydrological regimes by decreasing groundwater recharge, accelerating surface runoff, and increasing the vulnerability of high-intensity rainfall events to flooding (Eshtawi et al., 2016). The ensuing hydrological imbalance may cause ecological stress on biodiversity, disturb aquatic ecosystems, and deteriorate freshwater quality (Zhao et al., 2019). Seasonal variations in surface water dynamics also suggest instability in regional moisture systems, which could jeopardize water security and long-term climate resilience.

The divergent paths seen in Sylhet and Gazipur imply that environmental sensitivity and district-specific developmental pressures influence land transformation processes. As a result, rather than being consistent, sustainability solutions need to be context specific. To reduce ecological deterioration, it is imperative to strengthen integrated land use planning, enforce environmentally responsive zoning regulations, increase urban green infrastructure, encourage afforestation programs, and protect important water bodies. To prevent rapid urbanization from undermining long-term ecological stability and public health well-being, ecosystem-based frameworks can help strike a balance between economic expansion and environmental integrity.

4.3 Regional comparison and driving forces

The two districts show differing transformation regimes over the past two decades. Gazipur follows an industrial-urban expansion model, with significant growth in built-up areas and seasonal hydrological stress, indicating structural consolidation and insufficient vegetation recovery. In contrast, Sylhet displays a more ecologically sensitive trajectory, with potential summer vegetation recovery but a decline in water index values that suggests moisture stress. Recognizing these differences can foster appreciation for district-specific sustainability strategies, emphasizing the need for tailored interventions rather than uniform planning approaches.

The dynamics of land cover in Sylhet and Gazipur are indicative of broader patterns in South Asia, where growing urbanization and industrialization have led to increased impervious surfaces and a loss of vegetation (Hassan et al., 2021). Due to population growth and rural-to-urban migration, which have raised demand for housing and infrastructure and led to the conversion of agricultural land, Gazipur, an industrial hub, has experienced significant urban expansion. Extreme weather and climate fluctuation may further exacerbate vegetation stress by altering temperature and precipitation patterns, thereby influencing vegetation health and dynamics (Mehmood et al., 2024). To promote resilience and reduce ecological degradation, addressing these changes requires stronger urban environmental regulations, the integration of green infrastructure, and sustainable planning.

4.4 Limitations and future research

The research has several limitations, including spatial resolution, temporal gaps, a seasonal focus, a lack of validation constraints, limited socioeconomic integration, exclusion of climate change impacts, and reliance on GIS-based tools. Annual or short-term changes were not considered, and the transitional season that might have affected hydrological changes, such as the monsoon, was not included in the analysis. Additionally, the study relied heavily on satellite imagery-derived indices and GIS-based tools, which may introduce biases or errors due to atmospheric interference, cloud cover, or sensor limitations.

High-resolution satellite imagery in future research would be useful for documenting minor changes in water bodies, vegetation, and urbanization. Additionally, incorporating socioeconomic considerations can enhance understanding of land use dynamics. A regional comparison evaluating climate change parameters, such as temperature and rainfall, along with ground validation, will strengthen land use analysis.

5 Conclusion

This study shows that over the past 20 years, Sylhet and Gazipur have experienced changes in land cover due to urbanization and vegetation loss. The results emphasize the need for environmentally friendly urban development and sustainable land use governance. To increase ecological resilience, key considerations include maintaining water bodies, reducing impermeable surfaces, promoting urban afforestation, and safeguarding green spaces. To design climate-responsive zoning, implement sustainability measures, and inform planning decisions, policymakers can use remote sensing tools for spatial monitoring. Future studies should examine the relationship between land transformation and sustainability in metropolitan areas using high-resolution datasets and climate-linked models, highlighting the need to balance ecological health and economic expansion for long-term stability.

6 Data availability statement

The corresponding author can provide additional materials, such as processed datasets, analytical methods, and accompanying figures, following an appropriate request.

7 Ethical statements

This study does not require ethical approval.

8 Conflict of interest

The authors declare that they have no conflicts of interest.

9 Acknowledgement

The authors acknowledge the Department of Environmental Science and Engineering, JKKNIU, for providing research facilities. We truly acknowledge the use of geospatial data sources, including open-access satellite imagery.

10 Author contributions

T. Banik: Conceptualization, data curation, formal analysis, and writing – original draft. A. A. Seddique: Conceptualization, supervision, and writing – review & editing. All authors approved the published manuscript.

11 Copyright statement

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