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EVALUATION OF LAND SURFACE TEMPERATURE, VEGETATION DENSITY AND BUILT-UP LAND COVER CHANGES AFTER THE DEVELOPMENT OF THE BATANG INTEGRATED INDUSTRIAL ESTATE (KITB), CENTRAL JAVA

Nurhidayah[1*], Ahmad Hadi Ma'ruf[2], Rina Kurniati[3], Kasiyati[4]
[1]Environmental Science Master Program, School of Postgraduate Studies, Universitas Diponegoro, Indonesia
[2]Environmental and Urban Studies Master Program, School of Postgraduate Studies, Universitas Katolik Soegijapranata, Indonesia
[3]Department of Regional and Urban Planning, Faculty of Engineering, Universitas Diponegoro, Indonesia
[4]Department of Biology, Faculty of Science and Mathematics, Universitas Diponegoro, Indonesia
Email: hidayah@students.undip.ac.id[1*]

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Abstract

The development of the Batang Integrated Industrial Estate (KITB) since 2020 has triggered large-scale land transformation that has the potential to affect environmental biophysical conditions, particularly land surface temperature (LST), vegetation density (NDVI), and built-up land cover (NDBI). This study aims to evaluate the spatial and temporal changes in these three parameters during the 2019–2024 period and to analyze the statistical relationships among these variables. The data used consist of Landsat 8 and Landsat 9 satellite imagery for the years 2019, 2021, 2023, and 2024, which were processed to derive LST using the mono-window method, NDVI through the NIR–Red band combination, and NDBI using the SWIR–NIR bands. Spatial analysis was conducted through the mapping of the distribution of each parameter, while statistical analysis included descriptive statistics, Pearson correlation, and linear regression. The results indicate that the development of KITB has produced significant thermal and ecological impacts. LST increased from approximately 23–32°C in 2019 to 28–38°C in 2024, with higher temperature concentrations observed in the industrial core area and active construction zones. NDVI experienced a decline in areas that previously consisted of moderate to dense vegetation, particularly in the southern and western parts of the industrial estate, as indicated by the shift in NDVI map colors from green to brownish-red. Meanwhile, NDBI values showed a dominant increase in 2023–2024, corresponding to the expansion of built-up areas within the industrial zone. The correlation results show a strong negative relationship between NDVI and LST ($r < 0$), indicating that vegetation loss contributes to the increase in surface temperature. Conversely, a positive relationship was identified between NDBI and LST, suggesting that the expansion of built-up land cover contributes to surface warming. Overall, these findings confirm that the development of KITB has triggered significant increases in land surface temperature and vegetation degradation, highlighting the importance of green space management and thermal mitigation strategies in rapidly developing industrial areas.

Keywords: LST, NDVI, NDBI, KITB, Land use change, Spatial analysis, Statistical regression

INTRODUCTION

Land-use change driven by industrial estate development is one of the major drivers of alterations in environmental biophysical conditions across many developing countries. The conversion of vegetated land into impervious surfaces increases land surface temperature (LST), decreases soil moisture, and disrupts local ecosystem functions. This phenomenon has been widely documented in global studies, which consistently report that industrial and urban expansion is associated with rising LST and declining vegetation density, commonly quantified using the Normalized Difference Vegetation Index (NDVI). Similar patterns are evident in rapidly industrializing regions across Asia, where land conversion has led to the emergence of urban heat pockets and reduced thermal comfort for surrounding communities. In Indonesia, the development of industrial estates under the National Strategic Projects (PSN) framework has intensified since 2020. One of the largest developments is the Batang Integrated Industrial Estate

(KITB), covering approximately 4,300 hectares and designated as a nationally integrated industrial zone. The conversion of vegetated areas, settlements, and productive land into industrial zones has the potential to degrade environmental quality by increasing surface temperatures, fragmenting vegetated landscapes, and expanding built-up areas. Despite the rapid pace of KITB development and its direct influence on spatial transformation, scientific assessments of its biophysical impacts particularly the dynamics of LST, NDVI, and built-up land cover represented by the Normalized Difference Built-Up Index (NDBI) remain limited. Previous studies have demonstrated the effectiveness of integrating remote sensing with spatial–statistical analysis to identify environmental changes driven by development. Bagyaraj et al. (2023) documented a temperature increase exceeding 150% in the Kancheepuram industrial area, while Salan and Bhuiyan (2024) reported that urban expansion significantly reduces thermal comfort and increases LST. Oli et al. (2025) further confirmed these patterns by showing a positive relationship between built-up areas and rising LST, along with a negative relationship between NDVI and surface temperature. However, most existing studies have focused on metropolitan regions or long-established industrial centers, leaving the dynamics of newly developed industrial estates such as KITB insufficiently examined.

Several research gaps emerge from these conditions. First, no studies have specifically assessed changes in LST, NDVI, and NDBI within newly established large-scale industrial estates in Indonesia. Second, only limited research integrates spatial–temporal analysis with statistical approaches to assess the relationships among surface temperature, vegetation, and built-up land cover during the early stages of industrial development. Third, scientific evidence that can support environmental planning for subsequent phases of KITB development is still lacking. Therefore, this study aims to analyze changes in land surface temperature, vegetation density, and built-up land cover in the Batang Integrated Industrial Estate during the 2019–2024 period using remote sensing and spatial–statistical approaches. The findings are expected to provide comprehensive scientific insights into the biophysical impacts of spatial transformation and offer a reference for thermal mitigation and sustainable spatial management in newly developed industrial areas.

METHODOLOGY

This study employs a quantitative approach based on remote sensing and spatial–statistical analysis to evaluate changes in land surface temperature (LST), vegetation density (NDVI), and built-up land cover (NDBI) in the Batang Integrated Industrial Estate (KITB) during the 2019–2024 period. The primary dataset consists of Landsat 8 OLI/TIRS and Landsat 9 imagery obtained from the USGS Earth Explorer, selected using a cloud cover threshold of $<10\%$, with a spatial resolution of 30 m for reflective bands and 100 m (resampled to 30 m) for thermal bands. The study area was delineated through the digitization of a Region of Interest (ROI) encompassing approximately 4,300 hectares of the KITB area. Pre-processing steps included ROI clipping, radiometric and reflectance correction, conversion of digital numbers (DN) to radiance and brightness temperature, and cloud masking using the QA Pixel layer in accordance with USGS Collection 2 Level-1 standards. Environmental parameters were extracted by calculating LST using the mono-window method with NDVI-based emissivity correction (Bagyaraj et al., 2023; USGS, 2021), computing NDVI from Bands 5 and 4 to identify vegetation density levels, and deriving NDBI from Bands 6 and 5 to detect the intensity of built-up land cover. Each parameter was subsequently mapped thematically to illustrate the spatial distribution of surface temperature, vegetation cover, and built-up areas for each observation year. Statistical analysis included descriptive statistics (minimum, maximum, mean, and standard deviation), followed by Pearson correlation to assess the relationships between NDVI–LST and NDBI–LST. Simple and multiple linear regression analyses were then performed to quantify the influence of NDVI and NDBI on LST variability, following the approaches used by Salan & Bhuiyan (2024) and Oli et al. (2025).

RESULTS AND DISCUSSION

Spatial Analysis

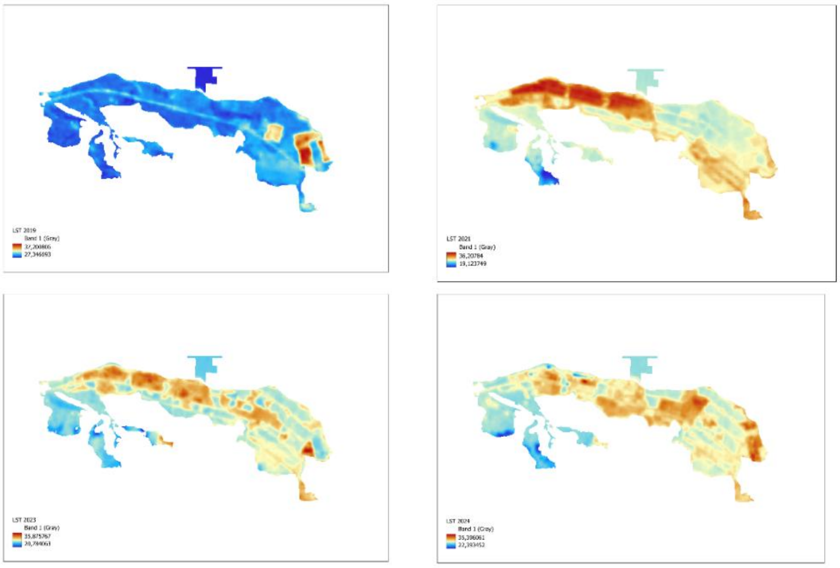


Figure 1. LST maps for 2019, 2021, 2022 and 2024.

The spatial mapping of land surface temperature (LST) reveals a consistent and progressive increase in thermal intensity across the KITB area throughout the 2019–2024 period. In 2019, temperature distribution remained within the low to moderate range (±27–30°C), indicated by the dominance of blue–green tones, reflecting pre-development conditions with extensive vegetated cover. High-temperature areas (>33°C) were still very limited and appeared only on exposed surfaces. This pattern aligns with the characteristics of densely vegetated landscapes that typically exhibit lower surface temperatures, as reported by Portela et al. (2020) and Hussain et al. (2023).

By 2021, there was a notable increase in high-temperature zones (30–35°C), particularly in areas undergoing land preparation for industrial construction. The color transition in the maps from blue to yellow–brown reflects vegetation loss and the expansion of impervious surfaces that absorb and retain heat. This increase in LST during the early development phase supports the findings of Bagyaraj et al. (2023), who emphasize that vegetation removal and the emergence of built-up surfaces are key drivers of rising land surface temperatures. In 2023, maximum temperatures remained high (>35°C), especially within industrial corridors experiencing intensive construction activities. However, lower temperatures persisted in the western and southern sections that retained vegetated cover. This thermal heterogeneity indicates that development not only elevates overall temperatures but also intensifies the thermal contrast between built-up and vegetated areas. Such patterns are consistent with the studies of Kagabo et al. (2024) and Salan & Bhuiyan (2024), which highlight how vegetation fragmentation amplifies urban heat island (UHI) intensity in rapidly developing zones. This condition reached its peak in 2024, with the industrial core zone dominated by spatially connected and expanding high-temperature clusters. The increasingly dominant orange–red tones indicate heat accumulation resulting from the expansion of hard surfaces such as buildings, asphalt, and dry exposed land. Conversely, vegetated areas maintained relatively low and stable temperatures, confirming their role as thermal buffers. These findings are in line with documented global UHI patterns in industrial regions, as reported by Meng et al. (2022) in China’s steel industrial belt and Singh & Kapoor (2025) in urban industrial areas of India.

The LST dynamics in KITB reinforce ecological relationships widely demonstrated in previous studies, namely that vegetation decline and expansion of built-up areas directly increase surface temperatures. The increasingly pronounced color contrast from 2019 to 2024 reflects not only the physical transformation of land but also the emergence of a localized thermal anomaly resembling an urban heat island (UHI) driven by rapid industrialization. This spatial trend is consistent with the statistical results of this study, which show a strong negative correlation between NDVI and LST and a strong positive correlation between NDBI and LST, confirming the functional relationship between land conversion and surface warming.

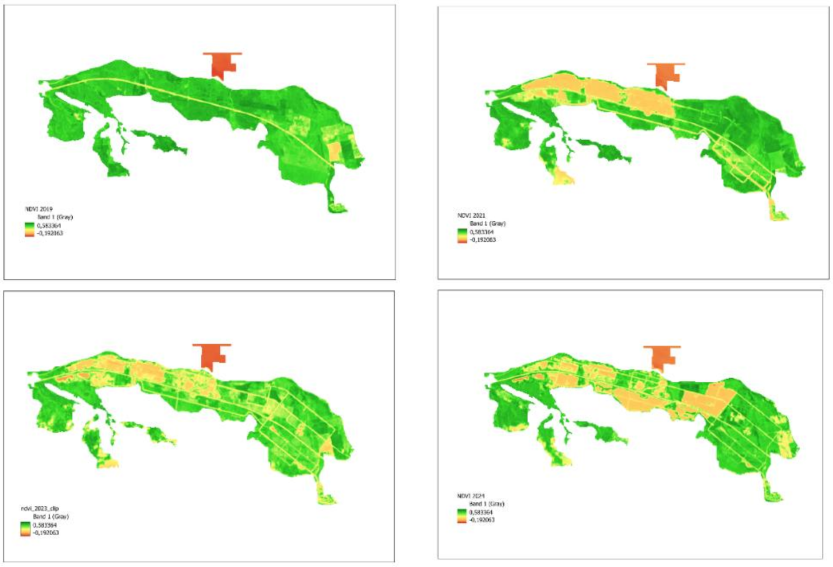
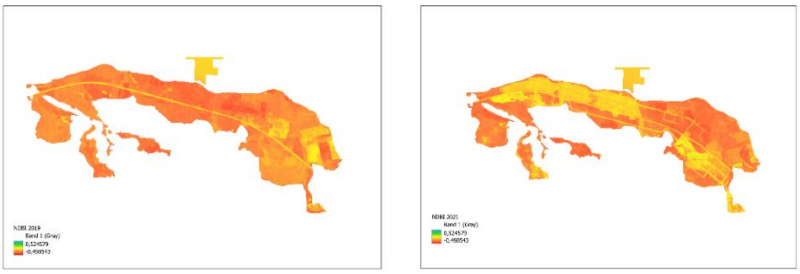


Figure 2. NDVI maps for 2019, 2021, 2022 and 2024.

The NDVI mapping illustrates a progressive degradation of vegetation in the KITB area during the 2019–2024 period. In 2019, the region was dominated by high NDVI values (0.3–0.5), representing healthy vegetation across agricultural land, dense shrubs, and natural cover. Non-vegetated areas were still very limited, consistent with low anthropogenic disturbance as noted by Hussain et al. (2023) and Yasin et al. (2024). A sharp decline began in 2021 when infrastructure development commenced; the core zone exhibited a color transition from green to yellow–orange, indicating biomass loss due to land clearing and grading activities. Initially localized degradation subsequently expanded into buffer areas, consistent with findings by Bagyaraj et al. (2023) and Reyes-Avila & Baxter (2024) regarding NDVI decline following large-scale land conversion. By 2023, low-NDVI areas continued to expand along road networks and industrial blocks, indicating systematic landscape restructuring, as also reported by Portela et al. (2020) and Meng et al. (2022). This condition reached its lowest point in 2024, with a mean NDVI of 0.30 and widespread yellow tones dominating nearly the entire industrial zone, while remaining vegetation persisted only in the western and southern parts of the area. Overall, the declining NDVI trend reflects the loss of key ecological functions—surface cooling, carbon absorption, and moisture retention—which typically diminish during transitions from vegetated surfaces to impervious land cover (Hussain et al., 2023; Reyes-Avila & Baxter, 2024; Rahimi et al., 2025). The consistent decrease in NDVI alongside the increase in LST further reinforces the NDVI–LST relationship widely demonstrated in previous studies, including Salan & Bhuiyan (2024), and explains the mechanism behind the emergence of a localized urban heat island within the KITB area.



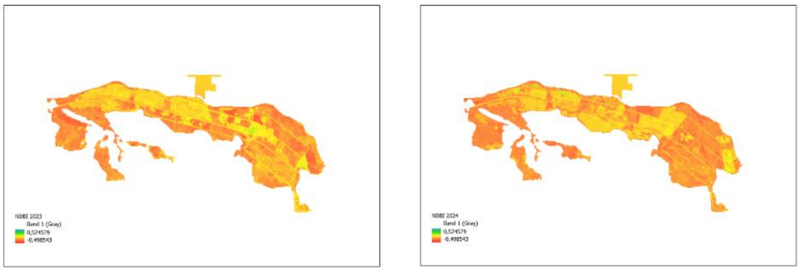


Figure 3. NDBI maps for 2019, 2021, 2022 and 2024.

The NDBI mapping results indicate a consistent increase in built-up areas within KITB throughout the 2019–2024 period. In 2019, NDBI values were predominantly negative, representing non-built-up land such as rice fields, plantations, and natural vegetation. By 2021, the emergence of positive NDBI values along major corridors and within the core zone signaled the onset of land clearing and site preparation activities. The expansion of areas with positive NDBI values became more pronounced in 2023, marked by the dominance of yellow–green tones, which indicates increasing impervious surfaces associated with industrial infrastructure development. This condition reached its peak in 2024, when most of the core KITB area had been converted into built-up surfaces. The pattern of increasing NDBI values aligns with the literature showing that the growth of built-up areas elevates NDBI values as a consequence of the expansion of hard, low-albedo surfaces (Zha et al., 2003; Portela et al., 2020). The increase in NDBI is also consistent with the decline in NDVI and the rise in LST over the same period, reinforcing the ecological relationship between land conversion, vegetation degradation, and increasing surface temperature as reported by Kagabo et al. (2024) and Meng et al. (2022). This indicates that the most substantial transformation of KITB's surface structure—reflected by rising NDBI values—occurred in parallel with the intensification of industrial development. The NDBI trend confirms the rapid morphological transformation of the landscape, where vegetation and wetland areas were replaced by large expanses of impervious surfaces. These changes directly influence the thermal dynamics of the region and highlight the contribution of industrial development to the formation of localized thermal hotspots. Thus, the NDBI analysis not only demonstrates an increase in built-up land but also strengthens the spatial relationship between industrial intensification and surface environmental changes within KITB.

Statistical Analysis

Descriptive statistical analysis (Table 1) shows that the mean LST fluctuated during the 2019–2024 period. The highest average temperature was recorded in 2019 (29.58°C), followed by a decline during the early development phase in 2021–2023, and subsequently increased again in 2024 to 29.16°C. Meanwhile, NDVI values exhibited a consistent downward trend from 0.41 in 2019 to 0.30 in 2024, indicating vegetation degradation in line with the expansion of built-up land. NDBI values increased from –0.22 in 2019 to –0.15 in 2024, reflecting a rise in built-up surface intensity.

Table 1. Descriptive Analysis of LST, NDVI, and NDBI

Variabel	Tahun	Mean	Min	Max	Std. Dev
LST	2019	29,58	27,68	37,15	1,37
	2021	28,57	20,31	35,45	2,70
	2023	28,19	22,84	33,82	1,92
	2024	29,16	23,42	34,57	1,84
NDVI	2019	0,41	0,09	0,51	0,06
	2021	0,34	0,04	0,51	0,14
	2023	0,32	0,03	0,49	0,11
	2024	0,30	0,02	0,49	0,14
NDBI	2019	-0,22	-0,33	-0,01	0,06
	2021	-0,18	-0,32	0,05	0,09
	2023	-0,15	-0,32	0,07	0,08
	2024	-0,15	-0,28	0,07	0,07

Spearman correlation analysis (Table 2) shows a significant negative relationship between NDVI and LST across all observation years (r = –0.563 to –0.715; p < 0.001), indicating that decreases in vegetation are associated with increases in surface temperature. Conversely, the relationship between LST and NDBI is positive and significant (r = 0.462 to 0.761; p < 0.001), suggesting that built-up areas exhibit higher surface temperatures.

Table 2. Spearman's Correlation Analysis

Tahun	LST – NDVI		LST – NDBI	
	r	p	r	p
2019	-0,563	<0,001*	0,462	<0,001*
2021	-0,715	<0,001*	0,761	<0,001*
2023	-0,563	<0,001*	0,733	<0,001*
2024	-0,635	<0,001*	0,708	<0,001*

The simple linear regression results (Table 3) show that NDVI has a significant negative effect on LST across all years, with negative regression coefficients (β = –0.768 to –0.525). This confirms the role of vegetation as a regulator of surface temperature. Conversely, NDBI has a significant positive effect on LST, with regression coefficients ranging from β = 0.635 to 0.688, indicating that increasing built-up intensity contributes to higher surface temperatures.

Table 3. Simple Linear Regression Analysis

Variabel	Tahun	Model Summary		ANOVA table		Coefficients table		
		R	R^2	F	Sig.	Konstanta	Koefisien β	Sig.
NDVI	2019	0,768	0,590	162,849	<0,001	36,271	-0,768	<0,001
	2021	0,708	0,501	113,64	<0,001	33,08	-0,708	<0,001
	2023	0,525	0,276	43,012	<0,001	31,040	-0,525	<0,001
	2024	0,570	0,325	54,416	<0,001	31,433	-0,570	<0,001
NDBI	2019	0,687	0,472	101,070	<0,001	32,899	0,687	<0,001
	2021	0,664	0,442	89,328	<0,001	32,086	0,664	<0,001
	2023	0,688	0,473	101,434	<0,001	30,508	0,688	<0,001
	2024	0,635	0,404	76,466	<0,001	31,699	0,635	<0,001

The multiple linear regression model (Table 4) shows that the combination of NDVI and NDBI simultaneously explains LST variability, with R^2 values ranging from 0.395 to 0.583. In 2019 and 2021, NDVI exerted the strongest negative influence on LST. However, in 2023 and 2024, the β coefficients for NDBI became more dominant, indicating that during the intensive development phase, the expansion of built-up land emerged as the primary factor driving increases in surface temperature.

Table 4. Multiple Linear Regression Analysis

Tahun	E	R^2	Adj. R^2	Uji F	Uji t		Koefisien β	
					NDVI	NDBI	NDVI	NDBI
2019	0,883	0,591	0,583	80,807	-5,695	0,291	-0,735	0,038
2021	1,895	0,516	0,507	59,694	-4,151	1,835	-0,515	0,228
2023	1,400	0,476	0,467	50,894	0,812	6,546	0,095	0,765
2024	1,430	0,405	0,395	38,144	-0,545	3,884	-0,080	0,566

The temporal trend analysis (Table 5) shows that all three variables (LST, NDVI, and NDBI) underwent significant changes from 2019 to 2024 (p < 0.001). NDVI and NDBI exhibit opposite patterns, in which vegetation decline is accompanied by an increase in built-up areas. This pattern runs parallel with the tendency of rising LST in response to land cover changes.

Table 5. Temporal Trend Analysis (2019–2024)

Variabel	2019	2021	2023	2024	p
LST	29,58	28,57	28,19	29,16	<0,001*
NDVI	0,41	0,34	0,32	0,30	<0,001*
NDBI	-0,22	-0,18	-0,15	-0,15	<0,001*

The statistical analysis indicates that the dynamics of surface temperature in KITB are a direct consequence of land cover changes throughout the 2019–2024 development period. The consistent decline in mean NDVI from 0.41 (2019) to 0.30 (2024) reflects the loss of vegetative biomass due to land clearing, grading, and construction activities. This trend aligns with the increase in NDBI values from –0.22 to –0.15, indicating the expansion of impervious surfaces such as roads, factory foundations, and industrial open land. These shifts reveal a structural transition of the landscape from vegetated ecosystems toward built environments, a mechanism widely described in the context of rapid urbanization (Portela et al., 2020; Meng et al., 2022). The statistical relationships among variables further clarify this ecological mechanism. The strong negative correlation between NDVI and LST ($r = –0.563$ to $–0.715$; $p < 0.001$) is consistent with the role of vegetation in providing cooling effects through evapotranspiration and natural shading. As NDVI decreases, evapotranspiration processes diminish, resulting in greater heat absorption and storage at the land surface. This mechanism aligns with findings by Hussain et al. (2023) and Rahimi et al. (2025), who emphasize that vegetation loss directly accelerates LST increases in urban and industrial regions. Conversely, the positive correlation between NDBI and LST ($r = 0.462$ to 0.761; $p < 0.001$) indicates that areas with extensive built-up surfaces exhibit higher surface temperatures. Impervious materials such as asphalt and concrete possess low specific heat capacity and low albedo, allowing them to absorb more radiative energy and release it slowly—characteristics that intensify the urban heat island (UHI) effect. These findings align with the studies of Kagabo et al. (2024) in Kigali and Bagyaraj et al. (2023) in Kancheepuram, both of which show that higher NDBI values are consistently associated with thermal hotspots.

Simple linear regression further reinforces these relationships: NDVI exhibits significant negative coefficients ($\beta = –0.768$ to $–0.525$), while NDBI shows significant positive coefficients ($\beta = 0.635$ to 0.688). This confirms that vegetation is the primary determinant of surface temperature in the early stages of development, but the dominance shifts towards built-up surfaces as industrial construction progresses. Multiple linear regression reveals a more complex dynamic in which NDVI exerts stronger influence on LST in 2019–2021, whereas NDBI becomes the dominant factor in 2023–2024 (β for NDBI reaching up to 0.765). This suggests that during intensive development phases, industrial structures and building materials become the primary thermal drivers. This pattern reflects a natural sequence of spatial transformation: initial temperature increases are driven by vegetation loss, but once extensive impervious materials are introduced, they become the main contributors to surface warming. The temporal trend patterns support this interpretation: NDVI decreases significantly, NDBI increases significantly, and LST—despite temporary fluctuations—ultimately rises again in 2024. The apparent decline in LST during 2021–2023 is more strongly influenced by the spatial distribution of cloud-covered pixels and the heterogeneity of wet, exposed ground surfaces, rather than a genuine ecological reduction in heat. This aligns with the explanation of Salan & Bhuiyan (2024), who note that early construction phases often produce temporary thermal variability due to the presence of moist soil, vacant land, and unfinished materials before permanent infrastructure is completed. Overall, the statistical results demonstrate that KITB's development has significantly altered the ecological and thermal structure of the region. The combined patterns of declining NDVI, increasing NDBI, and rising LST reflect the classic mechanisms of UHI formation in newly established industrial zones. The consistency between statistical analysis and spatial mapping strengthens the conclusion that industrialization is the primary driver of thermal changes in KITB, consistent with patterns observed in industrial regions across Asia and Africa (Bagyaraj et al., 2023; Kagabo et al., 2024; Salan & Bhuiyan, 2024). These findings underscore the need for vegetation-based spatial planning interventions and surface heat management strategies to mitigate thermal risks in rapidly developing industrial areas

CONCLUSION

This study demonstrates that the development of the Batang Integrated Industrial Estate (KITB) has caused significant alterations to surface environmental conditions during the 2019–2024 period. Land surface temperature (LST) tended to increase in line with the expansion of built-up areas, whereas vegetation density (NDVI) experienced a consistent decline. Meanwhile, NDBI values showed an increasing trend, indicating intensified development activities. The statistical analysis confirms a strong negative relationship between NDVI and LST, as well as a strong positive relationship between NDBI and LST. These findings emphasize that vegetation loss contributes to rising surface temperatures, while the expansion of built-up areas reinforces heat accumulation. Overall, the industrialization process in KITB has had a substantial impact on increasing surface temperatures and degrading the biophysical condition of the land, highlighting the need for vegetation-based mitigation strategies and spatial planning that is more adaptive to thermal changes in the area.

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