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An Integrated Assessment of the Land Use Change Impact on Climatic Factors and Water Quality in the Kalurghat Heavy Industrial Area, Chattogram

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Abstract

Land use change is one of the most pressing environmental issues globally, and its impacts on climate and water quality have received significant attention in recent years. This study conducted an integrated assessment of the land use change impact on climatic factors and water quality in the Kalurghat Heavy Industrial Area, Chattogram. This study utilized Landsat 5 data of 2003 & Landsat 8 data 2013 and 2023 to analyze land use change in the study area. The NDVI, NDBI indices method was used to detect the LULC change, which allowed us to identify the patterns and extent of land use changes over time. The results of the LULC analysis showed that the area has undergone significant land use change, with vegetative lands being converted to urban and industrial areas. To assess the impact of land use change on climatic factors, we analyzed the temperature data of the study area from 2003 to 2023, in 10 years interval. The results showed a significant increase in temperature and the level of stress in vegetation cover, indicating that land use change has had a significant impact on the local climate. This study also evaluated the water quality of the adjacent Karnaphuli river, a major water source for the surrounding communities. The study measured the concentrations of pH, Chlorophyll-a, Turbidity, EC, and Algal Density of the river water. The results of the water quality analysis showed that the water quality has deteriorated significantly due to the discharge of untreated industrial effluents into the river. This study highlights the importance of integrating land use change, climate, and water quality assessments for effective environmental management. The findings of this study could be useful for policymakers and land use planners in developing sustainable land use policies and management practices that can minimize the adverse impacts of land use change on the environment and public health. Overall, this study provides valuable insights into the impacts of land use change on climatic factors and water quality in the Kalurghat Heavy Industrial Area, Chattogram, and highlights the need for sustainable land use policies and management practices in the study area.

Keywords: *NDVI, LULC, Temperature, TSS, pH.*

1 Introduction

Industrialization has significantly altered the land use and land cover in Chattogram's Kalurghat Heavy Industrial Area. Concerns have been expressed regarding how these changes would affect the local communities quality of life and the environment (Das et al., 2020). This research seeks to perform an integrated evaluation of changes in land use and land cover and their impacts on the environment in the Kalurghat Heavy Industrial Area in order to address these issues. The significance of vegetation and waterbody quality for environmental stability and human well-being has been highlighted in earlier research. Ecosystem services provided by vegetation include carbon sequestration, erosion management, and the provision of habitat for biodiversity (Das et al., 2020). By affecting local temperature, humidity, and precipitation patterns, it also contributes to climate control. Additionally, the health of waterbodies is important for maintaining aquatic ecosystems, providing clean water supplies, and supporting a variety of economic activities, such as fishing and tourism (Jiang et al., 2023). Conducting an integrated evaluation of land use and land cover change in the Kalurghat Heavy Industrial Area is essential in light of the aforementioned effects of industrialization on vegetation, water quality, and land surface temperature. In order to thoroughly assess the various effects of land transformation on the natural environment, this study will make use of remote sensing techniques and various indices, such as the Normalized Difference Vegetation Index (NDVI), Normalized Difference Buildup Index (NDBI), Land Surface Temperature (LST), and Moisture Stress Index (MSI). In order to monitor and evaluate the environmental changes over time, a decadal change study of the years 2003, 2013, and 2023 will also be carried out using remotely sensed pictures. The findings of this study will shed important light on the scope and severity of changes to land use and land cover in the Kalurghat

Heavy Industrial Area. The results can also help stakeholders and decision-makers implement efficient land management and conservation methods to lessen industrialization's negative effects and advance sustainable development.

2. Study Area

Figure 01: Study Area Profile

The study area is a place with a lot of industrial and urban activity that is part of the Kalurghat Heavy Industrial Area in Chattogram. The research location, which is located in a coastal region of Bangladesh, is of great environmental value since it is close to the Karnaphuli River, a crucial water supply that sustains a variety of habitats (Kibria et al., 2016). The concentration of heavy industries, including as manufacturing, processing, and other industrial pursuits, in the Kalurghat Heavy Industrial Area is well-known. These businesses support the local economy but also present environmental problems such pollution, habitat loss, and land degradation (Mia et al., 2015).

The Karnaphuli River, which flows next to the study area, provides different ecological services and serves as a lifeline for the nearby population. However, runoff, other anthropogenic activity, and industrial effluents can pollute it. To evaluate the region's environmental sustainability and health, it is essential to comprehend the dynamics of water quality and how they relate to changes in land use. Overall, the research region offers a singular chance to look at how land transformation affects the ecosystem and water supplies. The study will shed light on the intricate relationships that exist between land use, vegetation cover, buildup settlement, land surface temperature, and water quality by concentrating on this industrialized and urbanized area. This will aid in the creation of sustainable management plans and environmental conservation initiatives .

3 Data & Methodology

3.1 Environmental Quality Assessment Methods

The assessment of environmental quality in this study involves the utilization of various indices and remote sensing techniques. The following methods were employed:
Normalized Difference Vegetation Index is a widely used vegetation index that measures the density and health of vegetation cover. It quantifies the difference between near-infrared and red reflectance values to assess vegetation abundance (Liu et al., 2023).

$$NDVI = (NIR - Red) / (NIR + Red) \quad (1)$$

Where:
NIR = Near-Infrared band reflectance
Red = Red band reflectance

Secondly, the Normalized Difference Buildup Index (NDBI is an index that evaluates the extent of built-up or urbanized areas within a study area. It compares the differences between shortwave infrared and near-infrared reflectance values to identify areas with increased human-made structures (Pradeep Kumar et al., 2023).

$$NDBI = (SWIR2 - NIR) / (SWIR2 + NIR) \quad (2)$$

Where:
SWIR2 = Shortwave Infrared 2 band reflectance
NIR = Near-Infrared band reflectance

Thirdly, the Moisture Stress Index (MSI) is an index used to assess moisture stress or water availability in vegetation. It combines near-infrared and mid-infrared reflectance values to quantify vegetation moisture content and stress levels.

$$MSI = (SWIR1 - NIR) / (SWIR1 + NIR) \quad (3)$$

Where:
SWIR1 = Shortwave Infrared 1 band reflectance
NIR = Near-Infrared band reflectance
And lastly, the Land Surface Temperature analysis involves the measurement of surface temperature using remote sensing data. It provides insights into the thermal characteristics of the study area and helps understand the urban heat island effect (Tahooni et al., 2023).

LST = K2 / ln((K1 / Thermal Band) + 1) ……………………..…………….……(4)

Where:
LST represents the Land Surface Temperature in Kelvin.
K1 and K2 are calibration constants specific to the Landsat sensor and thermal band used.
Thermal Band refers to the thermal infrared band values acquired from the Landsat image.

3.2 Spearman Correlation Analysis

To investigate the relationships among vegetation cover, buildup settlement, and land surface temperature, a Spearman correlation analysis was conducted. This non-parametric statistical method assesses the strength and direction of monotonic relationships between variables (Zhang & Wang, 2023).

3.3 Water Quality Assessment Methods

The assessment of water quality focused on the adjacent Karnaphuli River. The pH level indicates the acidity or alkalinity of the water, providing insights into its chemical composition and suitability for various aquatic organisms. Whereas, Turbidity measures the cloudiness or clarity of water, indicating the presence of suspended particles. It affects light penetration and can indicate the presence of pollutants. Then the, EC quantifies the ability of water to conduct electric current, reflecting its dissolved mineral content and salinity. Next, the Algal density, measured in remote sensing reflectance (Rrs) values, provides an estimation of the abundance of algae in the water. It serves as an indicator of water quality and eutrophication. Lastly, the Chl-a concentration is an important parameter for assessing water quality and the presence of phytoplankton. It indicates the level of primary productivity and can be used as an indicator of nutrient enrichment.

Table 5 Water quality assessment For Landsat 5 (2003)

Factors	**Band Combinations**	**Source**
EC	0.5185−0.3679/(b2/b3)	(Khattab & Merkel, 2013)
Turbidity	3 5.121−14.489(b2/b3)−0.911b4	
Chl-a	111.236−27.416(b1/b2)−70.17(b2/b1)−0.448b2	
pH	9.738−0.084b5	
Algal Density	11.771+0.051b4+0.555b1+0.089b5	

Table 2 Water quality assessment For Landsat 8 (2013, 2023)

Parameter	**Equation**		
EC	$EC = -6.6166 * \left(\frac{b2 - b3}{b4 - b6}\right) - 0.12025$		
Turbidity	$Log(Turbidity) = 10.26 * (b4 + b5) - 0.18359$		
pH	$pH = 11.987 + 422850000 * (B3)^{10} - 1263600000 * (B4)^{10} - 0.62664 * \left(\frac{1}{B5}\right) + 0.052596 * \left(\frac{1}{B6}\right) + 0.016603 * \left(\frac{1}{B5}\right)^2$		
Chl-a concentration	Landsat OLI	$B2/(B3 + B4)$	$y = -14.61 \times x + 10.98$
	Sentinel MSI	$B5 - (B4 + B6)/2$	$y = 2.57 \times e^{284.24 \times x}$
Algal density	Landsat OLI	$(B2 - B3)/(B2 + B3)$	$y = -12{,}502{,}445.57 \times x + 1{,}628{,}888.71$
	Sentinel MSI	$B5 - (B4 + B6)/2$	$y = 1{,}227{,}118{,}587.08 \times x + 2{,}142{,}593.11$

(González-Márquez et al., 2018)(Meng et al., 2022)

These assessment methods were applied to data collected for the years 2003, 2013, and 2023 to analyze the changes in environmental quality over time and understand the impacts of land transformation on the natural environment and water resources.

4 Results

4.1 Change of Buildup Settlement

This study's NDBI (Normalized Difference Buildup Index) assessment sheds light on how the buildup area has changed inside the Kalurghat Heavy Industrial Area between 2003 and 2023. Higher values indicate an increased number of built-up areas.

The NDBI measurements serve as a numerical representation of the number of built-up structures within the study region. The findings (figure 2) show a steep rise in NDBI values between 2003 to 2023, which suggests a significant growth of buildup regions inside the Kalurghat Heavy Industrial Area. The highest NDBI value ever observed in 2003 was 0.13, which shows a relatively constrained expanse of built-up surfaces.

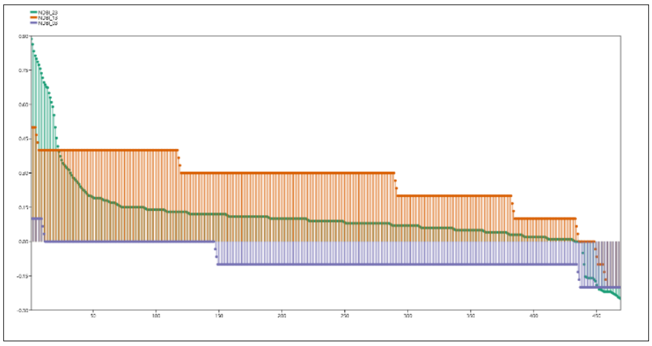

Figure 02: Comparison of NDBI Values from 2003 to 2023 in Kalurghat Heavy Industrial Area

The built environment had significantly expanded by 2013, as evidenced by the greatest NDBI value rising to 0.51 at that time. The accumulation area continued to significantly rise as a result of this tendency, reaching a maximum NDBI value of 0.90 in 2023. The rapid urbanization and industrialization that has resulted in the proliferation of built-up surfaces brings to light their negative environmental effects, such as habitat loss and fragmentation, changing microclimates, and potential effects on biodiversity.

4.2 Change of Vegetation Cover

Figure 3, provides representation of the dramatic decrease in NDVI values illustrates the detrimental effects of industrialization and changes in land use that affect vegetational canopy throughout the Kalurghat Heavily Industrialized Area. Natural vegetation is removed to for infrastructure and constructed surfaces as industries grow and cities grow. This removal of vegetation affects biological functions, lessens the amount of available habitat, and decreases biodiversity.

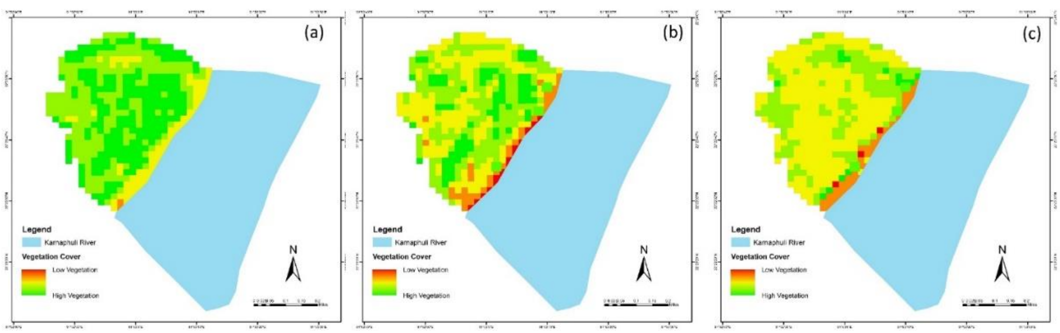

Figure 03: Rapid Decrease in Vegetation Cover in Kalurghat Heavy Industrial Area in years (a) 2003 (b) 2013 (c) 2023

4.3 Land Surface Temperature Change

The study conducted a comprehensive analysis of land surface temperature (LST) changes in the study area. The analysis focused on the years 2003, 2013, and 2023 to assess the temporal variations in temperature patterns. The LST values were obtained from Landsat images and were measured in degrees Celsius.

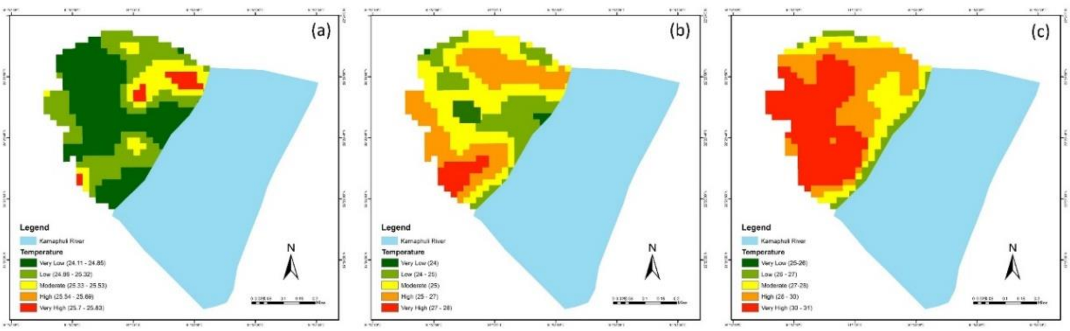

Figure 04: Rapid Increase in Temperature in Kalurghat Heavy Industrial Area in years (a) 2003 (b) 2013 (c) 2023

In the year 2003, the majority of the study area exhibited relatively low temperatures, ranging from 24.11 to 24.85 degrees Celsius. This indicated that a large portion of the land had a relatively cool surface temperature during that time.
Moving forward to 2013, significant changes in temperature patterns were observed. The study area experienced a shift towards higher temperatures, with the majority of the region falling within the moderate to high temperature range. This shift indicated an increase in the land surface temperature compared to the previous decade. The higher temperatures were likely influenced by various factors such as urbanization, changes in land cover, and increased anthropogenic activities, including industrialization in the area. In the final year of analysis, 2023, a notable escalation in land surface temperature was observed. The vast majority of the study area now fell within the very high-temperature zone, ranging from 30 to 31 degrees Celsius. This significant increase in temperature highlighted the intensification of heat accumulation and suggested a heightened thermal impact on the land surface. The findings suggested a clear trend of rising temperatures over the study period, with the year 2023 experiencing the highest temperatures among the three years analyzed. These observed changes in land surface temperature have important implications for the local environment and ecosystem. Higher temperatures can lead to increased evaporation rates, changes in vegetation dynamics, and potential impacts on wildlife habitats. Additionally, such temperature increases can exacerbate the urban heat island effect, contributing to uncomfortable living conditions and potential health risks for human populations in the study area.

4.4 Correlation Analysis

The correlation between the parameters examined for the years 2003, 2013, and 2023 is the main topic of Figure 5(a). The chart shows a correlation among buildup area and surface temperature of the land that is positive, showing that as construction settlement grows, land surface temperature also rises. The image also depicts a negative association between buildup area and vegetation cover, suggesting that as accumulation settlement grows, there is a decline in vegetation cover. These correlations emphasize how intertwined these elements are and support the conclusions of past investigations. The Kalurghat Heavy Industrial Area's steady loss of vegetative cover, quick growth of built-up areas, and subsequent increase in land surface temperature are all depicted visually in Figure 5(a) for the years 2003, 2013, and 2023. These developments highlight the negative effects of urbanization and industrialization on the environment.

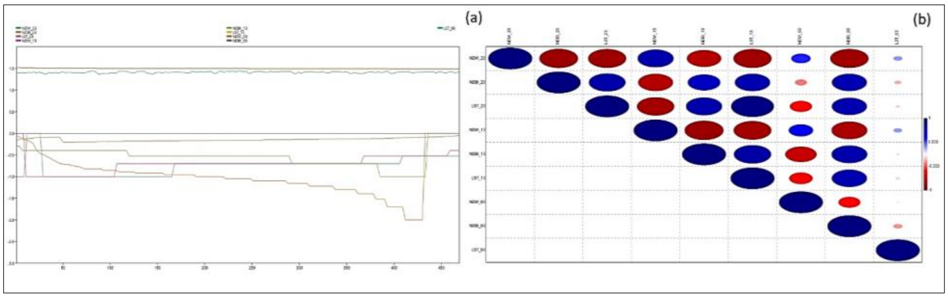

Figure 05: (a) Temporal Trends in Vegetation Cover, Buildup Settlement, and Land Surface Temperature; (b) Correlation Analysis of Factors: from the years of (2003, 2013, 2023)

These observations are further supported by Figure 5(b), which shows a positive correlation between accumulation area & land surface temperature as well as a negative correlation between buildup area and vegetation cover. The results highlight the necessity for environmentally friendly land management approaches that take into account how these variables interact in order to reduce the adverse environmental impacts of industrial expansion.

4.5 Assessment of the Quality of Water to the Adjacent River (Karnaphuli)

Using imagery from remote sensing and particular metrics for the periods of 2003, 2013, and 2023, the Karnaphuli River's water quality was assessed in the area of the Kalurghat, the industrial sector Area. The objective of this investigation was to compare the results with the established threshold for each parameter and assess how the quality of the water has changed over time.

Table 3 Water Quality Analysis of Karnaphuli River in the Kalurghat Heavy Industrial Area (2003, 2013, 2023)

Parameters of WQ	Years			Unit
	2003	2013	2023	
pH	7.92	8.23	10.45	
Chlorophyll-a	4.6	10.97	11.98	µg/L
Turbidity	2.3	5.08	7.8	NTU
EC	15.06	26.35	39.58	µS/cm
Algal Density	341313	16288	141313	Remote sensing reflectance (Rrs) value at a specific wavelength

Industrial Area underwent a water quality analysis, which found significant changes in a number of parameters over time. For pH, Chlorophyll-a content, turbidity, and electrical conductivity, deviations from the established criteria were found, suggesting possible effects of industrial operations and other factors on water quality. The varying algal density is another indicator of how dynamic the river environment is. These results emphasize the requirement for efficient management techniques and pollution prevention strategies to maintain and enhance the water's quality in the studied area.

5. Discussion

The analysis of land transformation using different indices and remote sensing techniques revealed significant changes in the study area over the years. The NDBI analysis indicated a substantial increase in buildup area from 2003 to 2023. This expansion of industrial settlements can exert stress on vegetational cover, as observed in the NDVI analysis. The gradual decrease in vegetation cover over the years, as shown in this study, can be attributed to the increasing buildup settlement and industrialization. These findings highlight the negative impact of industrialization on vegetational cover. The Spearman correlation analysis demonstrated significant relationships among vegetation cover, buildup settlement, and land surface temperature. The negative correlation between vegetation and buildup settlement indicates that as the buildup area increases, the vegetation cover decreases. Additionally, the positive correlation between buildup settlement and land surface temperature suggests that industrialization contributes to rising temperatures. Furthermore, the assessment of water quality in the adjacent Karnaphuli River highlighted the deterioration of water conditions over the years. The analysis of pH, turbidity, EC, algal density, and Chlorophyll-a levels indicated a decline in water quality, with increasing values beyond acceptable standards. This deterioration can be attributed to industrial activities and the associated discharge of pollutants into the river. Overall, the findings of this study emphasize the negative impacts of industrialization on the natural environment, including vegetation loss, increased land surface temperature, and degraded water quality. These findings underscore the importance of implementing sustainable land management practices, environmental regulations, and pollution control measures in industrial areas to mitigate these adverse effects.

6 Conclusion

In conclusion, our comprehensive analysis of changes in land use and land cover in Chattogram's Kalurghat Heavy Industrial Area has shed important light on the effects on the environment. The research employing various indices and methods for remote sensing has highlighted the complexity of environmental transitions by revealing considerable changes and linkages among numerous elements. According to the study's findings, there has been a noticeable increase in human settlements and a corresponding decline in plant cover over time, which has resulted in a distinct pattern of land alteration. Loss of biodiversity, changing microclimates, and an increase in land surface temperature are some of the negative effects of the growth of industrialized and urban regions on the ecosystem. The insights gained from this study can aid policymakers, environmental agencies, and stakeholders in making informed decisions regarding land use planning, environmental conservation, and sustainable development. By understanding the relationships among land transformation, vegetation cover, temperature changes, and water quality, effective strategies can be devised to promote environmental protection, preserve biodiversity, and ensure the well-being of both ecosystems and human populations.

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