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Article

Land use land cover changes from 2003 to 2023 using Remote Sensing and GIS techniques in Niamotpur Upazila with a predictive study for the next decade

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Abstract

This study aims to examine the temporal dynamics of Niamotpur Upazila, Naogaon District, focusing on Land Use Land cover (LULC) changes over thirty years (2003,2013, and 2023) and providing predictive insights for the next decade (2024÷2033). Utilizing Geographic Information System (GIS) techniques, remote sensing data, and meteorological datasets, we categorize the landscape into five primary land cover types: water bodies, vegetation cover, bare soil, drought-prone areas, and settlement areas. This study investigates the relationship between climatic factors and LULC changes, particularly examining the impacts of precipitation and temperature fluctuations on drought-prone areas. From 2003 to 2023 bare soil consistently decreased, while deep vegetation significantly increased, indicating improved land health. Urban areas and light vegetation peaked in 2013 but declined by 2023. Water bodies decreased until 2013, then increased by 2023. Drought-prone areas saw a drastic decrease in extreme drought and a substantial increase in no-risk areas. Climatic data showed minor fluctuations in average temperatures and precipitation: the average maximum temperature slightly decreased, while minimum temperatures and precipitation had small variations. Predictions for the next decade forecast a gradual rise in the average maximum temperature from 29.758 °C in 2024 to 29.830 °C in 2033. The findings underscore the positive trend of increasing deep vegetation and reducing bare soil, enhancing the region's ecological health. To address these trends the study offers practical recommendations for policymakers, stakeholders, and local communities. Ultimately, this study gives substantial insights into the relations between the dynamic alterations of LULC and climatic factors and presents a way of achieving a better future environment for Niamotpur Upazila.

Keywords: *LULC, adaptive strategies, Niamotpur upazila, GIS, remote sensing data, land use efficiency, meteorological datasets, sustainable development projects, infrastructure development*

INTRODUCTION

Land is a fundamental resource supporting all terrestrial ecosystems, driving agriculture, urbanization, and natural processes essential for human survival [1]. Over the past few decades, rapid urbanization, agricultural expansion, and environmental degradation have significantly altered global

LULC patterns [2. 3]. These changes are of particular concern in developing countries like Bangladesh, where population growth and land scarcity put tremendous pressure on natural resources [4]. Understanding the dynamics of LULC is crucial for achieving sustainable development and ensuring environmental security in regions experiencing rapid change.
Bangladesh's rich landscape surrounds Niamotpur Upazila, which offers a fascinating niche for understanding the complex dynamics of changing LULC in the context of shifting environmental challenges. Over the past decades, Niamotpur has undergone profound transformations in its land use patterns, spurred by a confluence of factors including rapid urbanization, agricultural expansion, and infrastructure development [5]. As a result of the rapid depletion of natural resources, which has altered the global land surfaces, human civilization has continued to advance and improve [6].
The study primarily centers on the delicate relationship between LULC changes and climatic variables with Niamotpur Upazila as the study area, from 2003 to 2023. The purpose of this research is to understand how the intertwining between human-prompted changes and climatic factors can be observed in the region of Niamotpur Upazila. The geo-referenced raw images are provided via satellite images [7]. Remote sensing has emerged as one of the key techniques for LULC mapping [8]. The approach choice is a comprehensive one combining GIS tools and remote sensing techniques. Satellite imagery is known mostly as the data source for mapping land use land cover generation [9]. Furthermore, the research examines the influence of climatic factors, such as precipitation and temperature fluctuations, on drought-prone areas and overall land health. The study provides a comprehensive understanding of how LULC changes correlate with these climatic variations, offering predictive insights for the next decade (2024–2033). The findings of this study will be critical for policymakers, urban planners, and environmentalists in crafting strategies that promote sustainable land management, enhance climate resilience, and mitigate the adverse effects of land degradation.
By investigating the complex interplay between human activities, land use, and climatic influences in Niamotpur Upazila, this research aims to contribute to the growing body of knowledge on sustainable land management. The study's findings will serve as a guide for future policy decisions aimed at balancing development needs with environmental conservation, thereby securing a more resilient future for the region.

METHODOLOGY

Study Area

Niamatpur is an upazila in Naogaon District, which is part of the Rajshahi Division, Bangladesh. It has 35299 households and a total area of 449.09 km2. Niamatpur Upazila is divided into eight union parishads: Bahadurpur, Bhabicha, Chandan Nagar, Hajinagar, Niamatpur, Parail, Rasulpur, and Sreemantapur. The union parishads are subdivided into 317 mazes and 344 villages. Figure 1 represents the study area map of Niamotpur Upazila.
Similar to other regions of Bangladesh, the economy of Niamotpur solely relies on agriculture and agricultural products. The farmers over there are much inclined towards the traditional forms of farming but there are certain unique modifications of modern farming [10]. Agriculture is the main source of employment for the inhabitants of Niamotpur, and because of the availability of good farms, different crops like wheat, rice, mustard, and vegetables can be grown here [11].
Although Niamotpur paints itself as a rural village par excellence, it is not entirely devoid of urban influence. Public schools, universities, medical facilities, and clinics are all sprinkled throughout the location, thereby ensuring the availability of essential services to the community. Over the years, infrastructural developments have brought the establishment of better roads, communication networks, and even accessibility to schools and hospitals which are essential needs of this area's people, thus improving the welfare of the people living in those regions [12].
The inhabitants of Niamotpur like all other local people of Bangladesh are famous for their hospitable and welcoming nature. Here, it is common to find people performing and even watching festivals, cultural activities, and sometimes religious practices [3, 13].

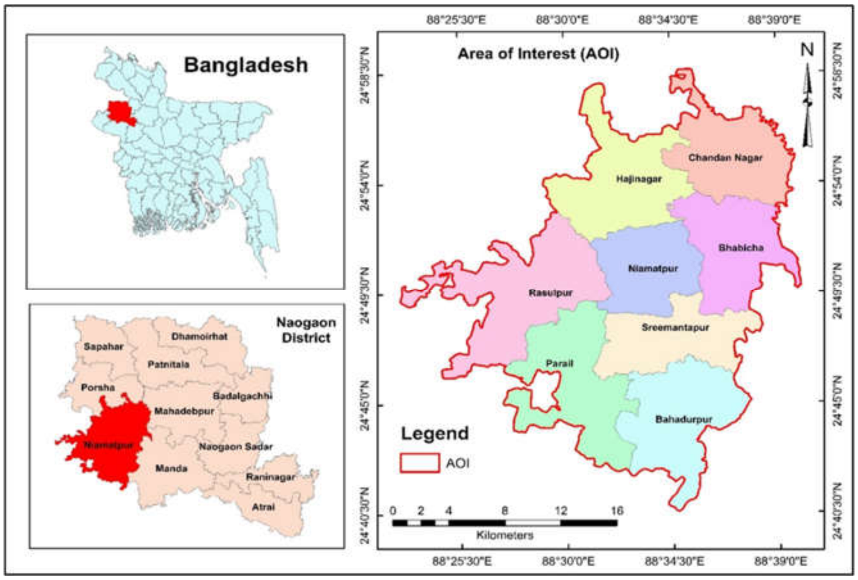

Fig.1. Study area map of Niamotpur Upazila

Satellite image sourcing processes

Figure 2 represents a workflow for processing satellite images, particularly focusing on drought analysis using various remote sensing techniques. The initial input is a satellite image, which serves as the primary data source for further analysis. Combining multiple spectral bands of the satellite image to create a composite image. That is called band composite. Then identifying and isolating the specific area of interest from the composite image. Image classification is classifying the pixels in the extracted area into different land cover types or categories based on their spectral signatures. Finally, the classified map shows different land cover types.

The Niamotpur region's land use and land cover classes are the land surface temperature is not the same as the air temperature that is included in the daily weather report [14]. For LST, apply a mask using Band 6 from Landsat 5 data, which is often used for thermal imaging. Converting digital numbers (DN) from the satellite image to radiance values, which represent the actual amount of light reflected or emitted from the surface. After that, radiation converges with temperature, and finally, the map shows the temperature distribution across the area of interest.

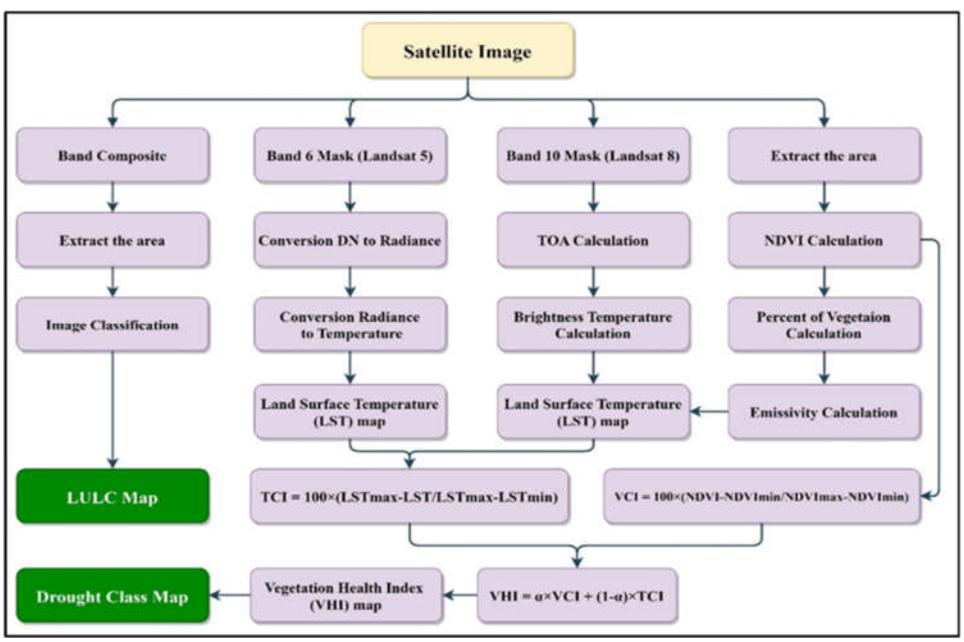

Fig.2. Satellite image sourcing processes

The second process for the LST map was to calculate LST from satellite imagery. Landsat 8 Operational Land Imager and Thermal Infrared Sensor (OLI-TIRS) sensor images were used. LST has been calculated using different formulas in different stages. We have prepared a model in the ArcGIS model builder to calculate the LST by combining different tools from ArcToolbox. The formula used to calculate LST was adopted by [15, 16].

Calculating the Vegetation Health Index (VHI), which combines the Normalized Difference Vegetation Index (NDVI) and temperature data to assess vegetation health, the temperature data from LST maps and vegetation data are combined to create the VHI map. Finally, the VHI map is used to classify the area into different drought classes. This map categorizes the area into different drought classes (e.g., no drought, light drought, moderate drought, severe drought, and extreme drought).

Table 1. Variable description and data sources

No.	Data sets	Variables	Cloud cover	Resolution
1	LC08_L1TP_138043 (2023)	LULC, VHI	10 %	30 m
2	LC08_L1TP_138043 (2013)	LULC, VHI	10 %	30 m
3	LT05_L1TP_138043 (2003)	LULC, VHI	10 %	30 m

Table 1 summarizes records about three distinctive fact sets. Each fact set relates to satellite pix captured inside the identical geographical region, identified using the direction/row code 138043, but from specific years, namely 2023, 2013, and 2003. The information units are identified by using their unique codes, including LC08_L1TP_138043 from 2023 and 2013 taken with the aid of the Landsat eight satellite, and LT05_L1TP_138043 for photos from 2003 taken through the Landsat five satellite. Two variables are protected for every record set: LULC and VHI. The cloud cover percentage is consistent across all records units at 10%, indicating that 10% of every picture is obscured with the aid of clouds, which is a thing that can affect the clarity and usability of the satellite facts. The spatial resolution of all the snapshots is 30 meters, meaning each pixel inside the picture represents a 30 by 30-meter region at the ground. This decision is ordinary for Landsat images and is adequate for unique environmental and land use studies.

In summary, Table 1 offers a concise contrast of satellite imagery records sets from 3 exclusive years (2023, 2013, and 2003), all taken over identical geographical areas with steady variables, cloud cover, and resolution. This information is beneficial for longitudinal studies of land use and vegetation health.

Calculations percentage change

To predict the next 10 years of LULC data, we can use linear extrapolation based on the given data from 2003, 2013, and 2023. This approach assumes that the trends observed over the past 20 years will continue in the same manner.

First step, was to calculate the annual change rate for each LULC class between 2003, 2013, and 2023. Then, was extrapolate these rates to predict the values for the years 2024 to 2033.

For calculate annual change rates was used formula (1):

$$\text{annual change rate} = (\text{value } 2023 - \text{value } 2003) / (2023-2003) \quad (1)$$

To predict de value of percentage change in 2023, was used formula (2):

$$\text{predicted value } 2033 = \text{value } 2023 + (\text{annual change rate} \times 10) \quad (2)$$

RESULTS

Figure 3 presents data on land use land cover categories (bare soil, deep vegetation, urban area, light vegetation, and water bodies) across three different years (2003, 2013, and 2023). There has been a continuous and significant decrease in bare soil over the years, dropping from 140.82 in 2003 to just 19.04 in 2023. On the other hand, deep vegetation has shown a consistent and substantial increase over the years, more than doubling from 63.82 in 2003 to 171.88 in 2023. The contiguous urban area increased from 52.69 in 2003 to 79.66 in 2013 but then decreased to 56.12 in 2023, indicating some fluctuation over the years. The broadside on light vegetation increased significantly from 124.39 in

2003 to 183.62 in 2013 before decreasing to 146.38 in 2023. Finally, water bodies decreased dramatically from 64.40 in 2003 to 16.72 in 2013, but then increased again to 52.71 in 2023 (Fig. 3). So, based on the analysis of the land use land cover map from 2003 to 2023, the bare soil has consistently decreased over the years. Deep vegetation is a consistent and significant increase. The most dramatic changes were in bare soil and deep vegetation, with bare soil decreasing significantly and deep vegetation increasing substantially. Urban areas increased from 2003 to 2013, then decreased by 2023. Light vegetation increased from 2003 to 2013, followed by a decrease by 2023. Urban area and light vegetation both peaked in 2014, with subsequent decreases by 2023. Finally, water bodies decreased from 2003 to 2013, followed by an increase by 2023. Water bodies showed a notable decrease in 2013 but recovered somewhat by 2023.

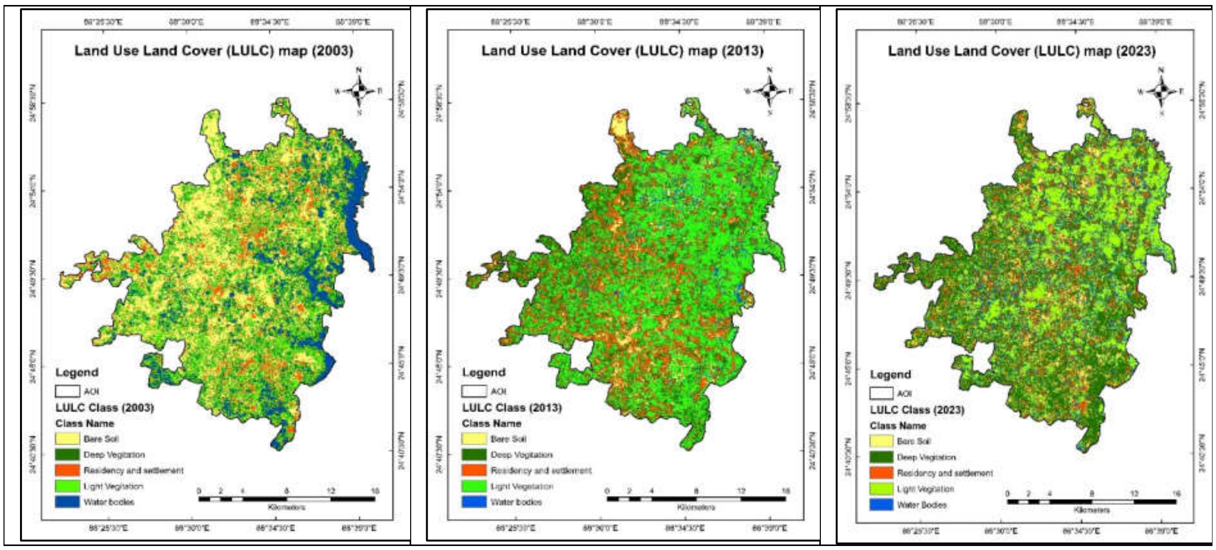

Fig. 3. Spatial distribution of LULC over Niamotpur region in (2003 ÷ 2023)

Yearly LULC change trends

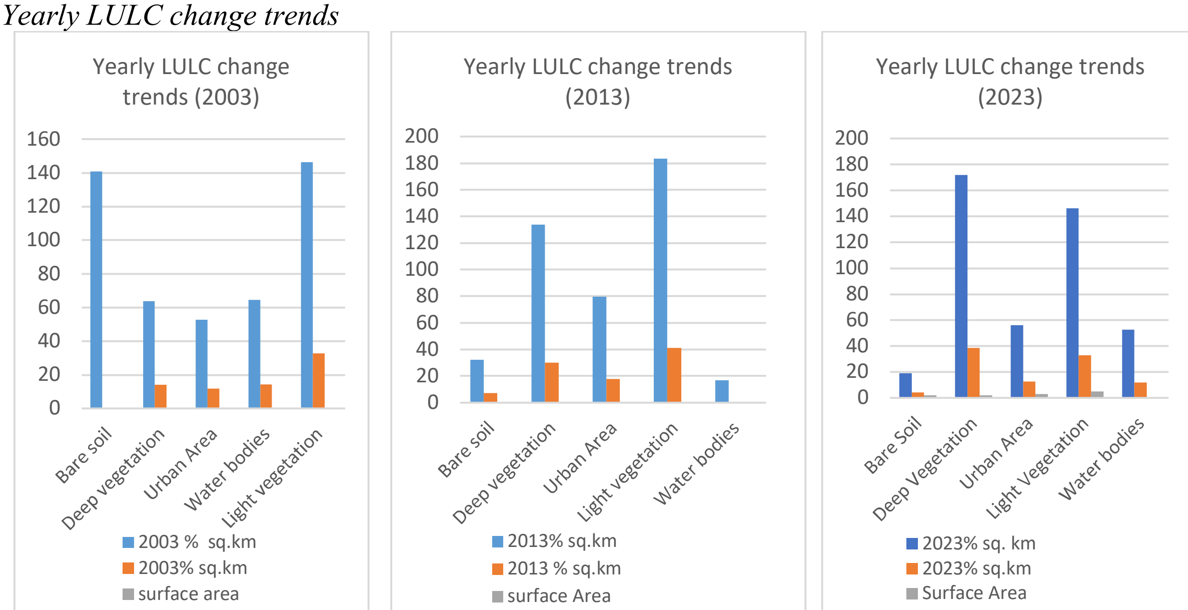

Fig. 4. Yearly LULC change patterns in Niamotpur Upazila (2003, 2013, 2023)

Figure 4 shows that the yearly land use land cover (LULC) analysis changes patterns over two decades, which indicates considerable landscape shifts between 2003 and 2023. In 2003, the major land cover was bare soil, accounting for 140.82 square kilometers (sq. km) (31.57%), followed by light vegetation with 124.39 sq. km (27.88%) and deep vegetation with 63.82 sq. km (14.3%). Urban areas and aquatic bodies accounted for 52.69 sq. km (11.81%) and 64.4 sq. km (14.44%), respectively. By 2013, bare soil had decreased to 32.35 sq. km (7.25%), while light vegetation had spread to 183.62 sq. km (41.16%), and deep vegetation had increased to 133.77 sq. km (29.99%). Urban areas expanded to 79.66 sq. km (17.86%), while water bodies contracted to 16.72 sq. km (3.75%). In 2023, the trend continued with bare soil further decreasing to 19.04 sq. km (4.27%), and deep vegetation reaching 171.88 sq. km (38.53%). Light vegetation slightly reduced to 146.38 sq. km (32.81%), and urban areas slightly decreased to 56.12 sq. km (12.58%). However, water bodies saw a resurgence, covering 52.71 sq. km (11.82%). These trends suggest a significant shift from bare soil to vegetation, indicating an increase in green cover and possibly improved land management practices, though urbanization has also progressed notably. The fluctuations in water bodies' extent highlight changing water management or climatic conditions affecting the area.

Drought-prone area over Niamotpur region in (2003÷2023)

Figure 5 represents the Graphical show of drought-prone areas over the Niamotpur region in (2003 ÷2023). So, based on the analysis of the vegetation health index for the drought calculation, the extreme category drought area has experienced a consistent and dramatic decrease over the years. However severe-category drought areas increased from 2003 to 2013, followed by a decrease in 2023. As well as a moderate-category drought area, there has been a continuous and substantial increase over the years. Serried light category drought area increased from 2003 to 2013, followed by a decrease in 2023. Finally, the no-risk (NR) category drought area has shown a continuous and substantial increase over the years.

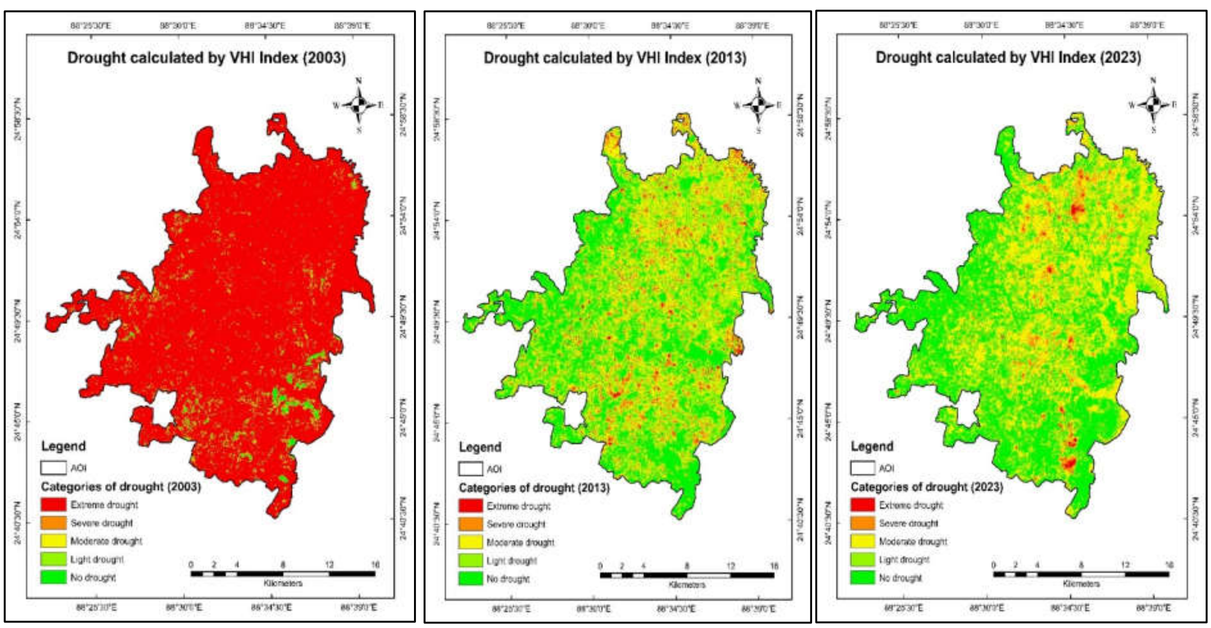

Fig. 5. Graphical show of drought-prone area over Niamotpur region in (2003÷2023)

The most dramatic changes were in the extreme category drought area, which decreased drastically, and the no-risk (NR) category drought area, which showed significant increases. Moderate category drought areas and Light category drought areas increased substantially from 2003 to 2013, but while Moderate continued to increase, Light decreased in 2023. Finally, the severe category drought area showed a more moderate change, with an increase in 2013 followed by a decrease in 2023.

Categories of Extreme, Severe, Moderate, Light, and NR

Figure 6 presents data on categories (Extreme, Severe, Moderate, Light, and NR) across three different years (2003, 2013, and 2023). The Extreme category drought area showed a continuous and dramatic decrease over the years, from 406.79 in 2003 to 2.36 in 2023. On the other hand, the severe category drought area increased from 18.09 in 2003 to 35.89 in 2013, then slightly decreased to 22.83 in 2023. Along the way, the moderate-category drought area showed a significant and continuous increase from 10.12 in 2003 to 144.41 in 2023. As well, the light category drought area also increased significantly, from 5.59 in 2004 to 141.70 in 2013, before decreasing to 103.80 in 2023. Finally, the NR category drought area saw a substantial increase over the years, from 5.54 in 2003 to 142.52 in 2013, and further to 172.72 in 2023.

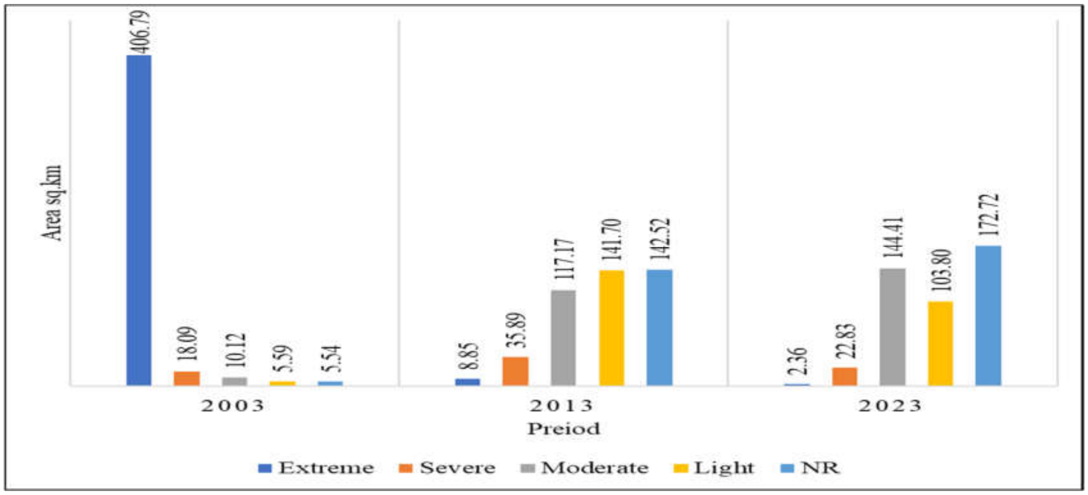

Fig. 6. Categories of Extreme, Severe, Moderate, Light, and NR (2003, 2013, and 2023)

Figure 7 represents that the 2003 to 2023, bare soil and water bodies significantly decreased by 121.78 sq. km (86.52%) and 11.69 sq. km (18.15%), respectively. In contrast, deep vegetation saw a substantial increase of 108.06 sq. km (169.26%), while light vegetation and urban areas also grew by 21.99 sq. km (17.68%) and 3.43 sq. km (6.51%). These changes highlight a notable shift towards increased vegetation and reduced bare soil and water bodies over the 20 years.

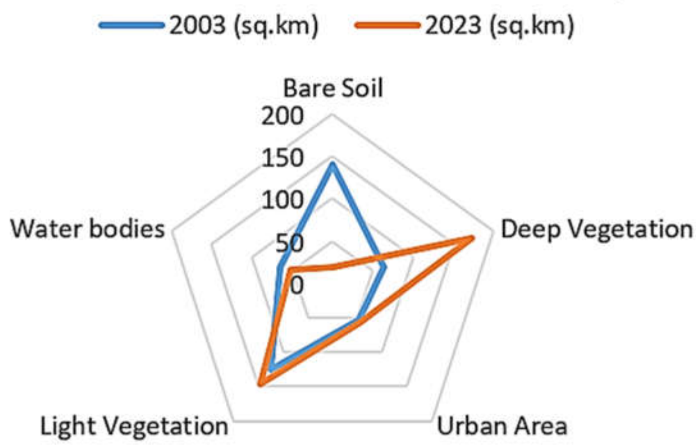

Fig. 7. Total changes in land cover from 2003 to 2023

Table 2 presents the annual change rates in land use and land cover (LULC) classes from 2003 to 2023. Bare soil experienced a significant decrease with its percentage dropping from 31.57% in 2003 to 4.27% in 2023, resulting in an annual change rate of -1.362% per year. Conversely, deep vegetation showed substantial growth increasing from 14.30% to 38.53% over the same period, corresponding to an annual change rate of 1.7115% per year.

Table 2. Annual change rate

LULC Class	2003%	2023%	Annual change rate (% per year)
Bare Soil	31.57	4.27	$\frac{4.27-31.57}{20}=-1.362$
Deep Vegetation	14.30	38.53	$\frac{38.53-14.30}{20}=1.7115$
Urban Area	11.81	12.58	$\frac{12.58-11.81}{20}=0.0385$
Light Vegetation	27.88	32.81	$\frac{32.81-27.88}{20}=0.2465$

The urban area exhibited a slight increase, rising from 11.81% to 12.58%, which translates to an annual change rate of 0,0385% per year. Light vegetation also shows an increase, with its percentage growing from 22.88% to 32.81% reflecting an annual change rate of 0.2465% per year. This change indicates a trend towards decreased Bair soil and increased vegetation cover, alongside modest urban expansion reflecting significant ecological and developmental transformation over the two decades.

Precipitation and temperature analysis

Table 3 provides a concise summary of the yearly average weather conditions for the years 2003, 2013, and 2023. Each row corresponds to a specific year, and each column presents key weather metrics. In terms of temperature, the "Avg Max Temp (°C)" column indicates the average maximum temperature recorded throughout the year, while the "Avg Min Temp (°C)" column represents the average minimum temperature. These values offer insights into the typical temperature range experienced annually.

Furthermore, the "Avg Precipitation (mm)" column denotes the average precipitation measured in millimeters yearly. This metric indicates the average rainfall or snowfall throughout the year.

Table 3. Yearly average temperature and precipitation (2003, 2013, and 2023)

Year	avg max temp (ºC)	avg min temp (ºC)	avg precipitation (mm)
2003	30.08	19.33	3.45
2013	29.67	19.42	2.12
2023	29.75	18.83	3.39

For instance, in 2003, the average maximum temperature stood at approximately 30.08°C, with an average minimum temperature of around 19.33°C. The average precipitation for the year amounted to about 3.45 millimeters. Similarly, in 2013, the average maximum temperature was roughly 29.67°C, the average minimum temperature was about 19.42°C, and the average precipitation was approximately 2.12 millimeters. Lastly, in 2023, the average maximum temperature was recorded at around 29.75°C, with an average minimum temperature of about 18.83°C. The average precipitation for the year totaled approximately 3.39 millimeters.

These yearly averages provide valuable insights into the typical weather patterns and climatic conditions experienced over the specified years.

Figure 8 shows a comparative analysis of temperature data (2003, 2013, 2023). In 2003, the observed maximum temperature peaked at 30.08°C, slightly surpassing the assumed long-term average of 30°C. Conversely, the observed minimum temperature of 19.33°C fell below the long-term average of 20°C, indicating a cooler-than-average condition. This discrepancy is further highlighted by the calculated temperature anomalies, with a slight positive anomaly for maximum temperature and a more pronounced negative anomaly for minimum temperature.

In 2013, both observed maximum and minimum temperatures exhibited deviations from their long-term averages. The maximum temperature of 29.67°C was slightly below the long-term average, while the minimum temperature of 19.42°C displayed a more notable shortfall. These variations are quantified through temperature anomalies, revealing negative anomalies for both maximum and minimum temperatures, albeit to a lesser extent compared to 2003.

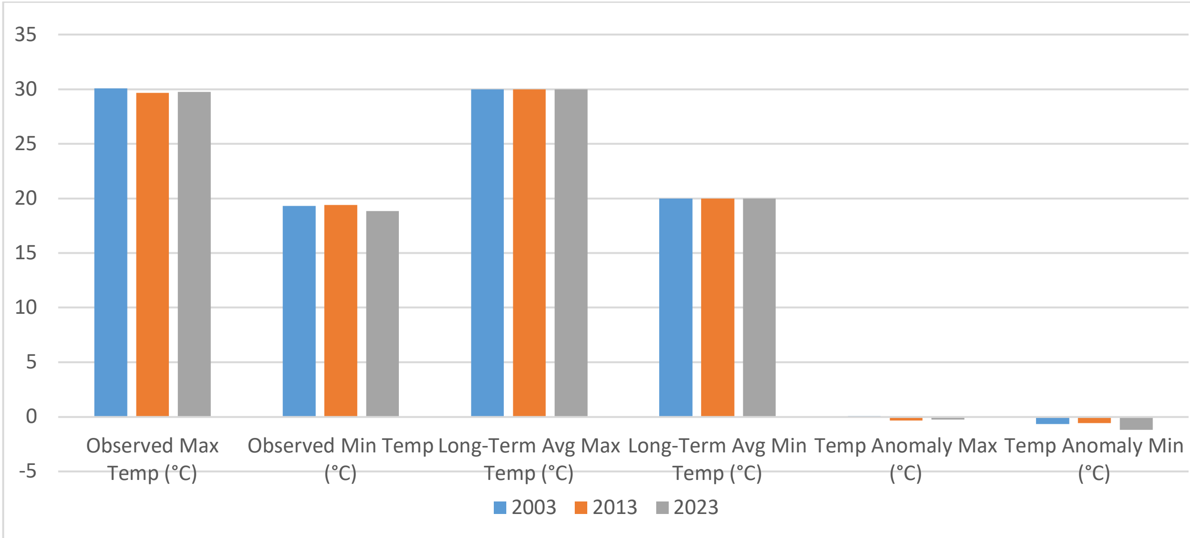

Fig. 8. Comparative analysis of temperature data regarding temperature anomaly (2003, 2013, 2023)

In 2023, a similar trend of temperature anomalies persisted. The observed maximum temperature of 29.75°C again fell slightly below the long-term average, reflecting a negative temperature anomaly. Notably, the observed minimum temperature dropped to 18.83°C, indicating a significant departure from the long-term average. This substantial deviation is captured in the temperature anomaly, showcasing a notable negative anomaly for minimum temperature.

Overall, the comparison of observed temperatures with long-term averages unveils fluctuations in temperature patterns over the specified years. These temperature anomalies serve as crucial indicators of climatic variability, aiding in the assessment of climate trends and their potential impacts. Through meticulous analysis of temperature data, researchers can glean insights into climate dynamics, informing strategies for adaptation and resilience-building in the face of changing environmental conditions.

Extrapolate for the next 10 years (predicted percentages for 2033)

According to table 4 there will be notable changes in LULC between 2023 and 2033, which will reflect both anthropogenic and dynamic natural processes. Bare soil, which made up 4.27% of the land in 2023, is predicted to decline by -1.362% each year by 2033 when it will have significantly decreased to around -9.93% of the land. With deep vegetation expected to cover 38.53% in 2023, yearly growth of 1.7115% is predicted, culminating in a notable increase to around 55.645%. Urban areas, which will make up 12.58% of the total in 2023, will expand at a minimum rate of 0.0385% each year, or around 12.965% by 2033. Light vegetation, which made up 32.81% of the total in 2023, is predicted to increase by 0.2465% a year to 35.275%. Furthermore, it is anticipated that water bodies, which comprise 11.82% in 2023, will decline by -0.131% each year to 10.51% by 2033. These estimates demonstrate the effects of land management methods and environmental changes during the decade, showing considerable gains in plant cover, consistent urban expansion, and a minor drop in water bodies.

Table 4. Predicted percentages for 2033

LULC Class	2023 %	Annual Change Rate (% per year)	2033 %
Bare Soil	4.27	-1.362	−9.93
Deep vegetation	38.53	1.7115	55.645
Urban Area	12.58	0.0385	12.965
Light vegetation	32.81	0.2465	35.275
Water Bodies	11.82	-0.131	10.51

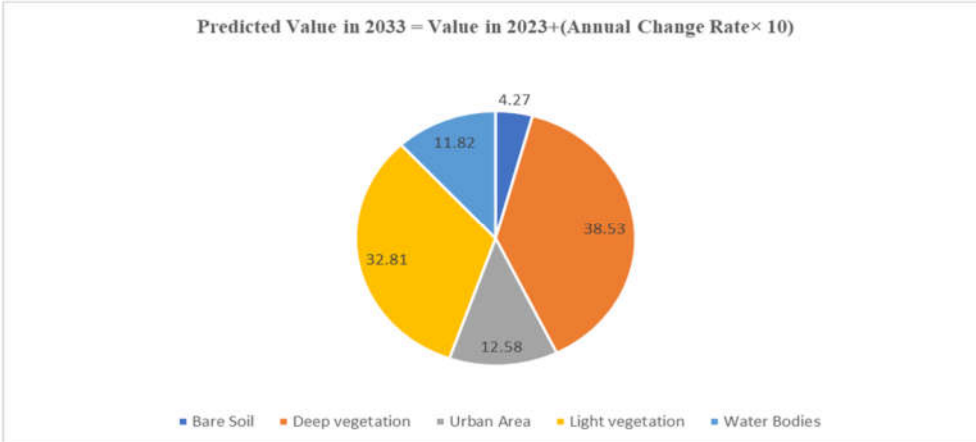

Fig. 9. Predicted value in 2033

It is improbable that the percentage of bare soil will reach negative by 2033, as shown in Fig. 9. This illustrates the possibility that Bare Soil is in danger of going extinct if the present situation continues. The establishment of deep and light vegetation indicates a tendency towards higher green cover. In the urban region, there has also been a slight increase. Nevertheless, the number of bodies of water is decreasing relatively slowly.

Predicted analysis 2024 to 2033

According to table 5 there will be notable changes in LULC between 2023 and 2033. These changes will be a result of both anthropogenic and biological processes. Starting at 4.27% in 2023, bare soil is predicted to gradually decline to 2.908% by 2024, -2.54% by 2028, and a significant fall to -9.93% by 2033. Starting at 38.53% in 2023, deep vegetation is expected to develop robustly, with projections showing that it will reach 40.2415% by 2024, 47.0875% by 2028, and a considerable 55.645% by 2033. Urban areas are projected to rise slightly from 12.58% in 2023 to 12.6185% in 2024, 12.7725% in 2028, and 12.965% in 2033, reflecting a regulated rate of urban expansion. As a result of steady ecological succession, light vegetation will rise from 32.81% in 2023 to 33.0565% by 2024, 34.0425% by 2028, and 35.175% by 2033. Water bodies are predicted to show a modest reduction, starting at 11.82% in 2023 and going down to 11.689% by 2024, 11.165% by 2028, and 10.51% by 2033. These forecasts show noteworthy patterns in the changes in land cover during the past ten years, caused by both natural and man-made factors.

Table 5. Predicted Environmental Trends (2024, 2028, 2033), %

Year	Bare Soil	Deep Vegetation	Urban Area	Light vegetation	Water Bodies
2024	2.908	40.2415	12.6185	33.0565	11.689
2028	−2.54	47.0875	12.7725	34.0425	11.165
2033	−9.93	55.645	12.965	35.175	10.51

Table 6 shows how, during ten years, from 2024 to 2033, we analyzed changes in land cover percentages across several categories. The data indicates significant changes in land use patterns: deep vegetation consistently increases from 40.24% in 2024 to 55.65% in 2033, demonstrating a tendency towards denser plant cover, whereas urban areas and aquatic bodies retain relatively steady proportions. On the other hand, there is a trend towards a decline in exposed soil and sparse vegetation. This transition demonstrates how land cover is dynamic and affected by a variety of variables, including urbanization, ecological management techniques, and climate change. In light of continuous environmental difficulties, understanding these shifts is essential for successful land use planning and conservation initiatives.

Table 6. Predicted table for 2024 to 2033, %

Year	Bare Soil	Deep Vegetation	Urban Area	Light Vegetation	Water Bodies
2024	2.908	40.2415	12.6185	33.0565	11.689
2028	-2.54	47.0875	12.7725	34.0425	11.165
2033	-9.93	55.645	12.965	35.275	10.51

Figure 10 shows that bare soil with a projected percentage of 2.908% in 2024 is expected to be even less than its already low 2023 number. In 2028, the projected percentage falls to -2.54%, indicating that the linear extrapolation may result in almost complete disappearance or extremely low levels of bare soil. The downward trend persists through 2033, hitting -9.93%. Throughout the projected period, it is anticipated that the percentage of deep vegetation will continue to rise slowly. It is predicted to climb significantly from 2023 to 40.2415% by 2024. The growth trend is expected to continue, reaching 47.0875% by 2028 and 55.645% by 2033, indicating a persistent increase in wooded or densely vegetated regions. It is anticipated that the percentage of urban areas will expand moderately, hitting 12.6185% by 2024, 12.7725% by 2028, and 12.965% by 2033. Although at a slower rate, the proportion of light vegetation is predicted to rise continuously, much like that of deep vegetation. It is expected to increase to 33.0565% by 2024, then 3.0425 percent by 2028, and 3.2775 percent by 2033. Throughout the predicted period, the proportion of water bodies indicates a small drop. It is expected to reach 11.689% by 2024, then drop even further to 11.165% by 2028 and 10.51% by 2033.

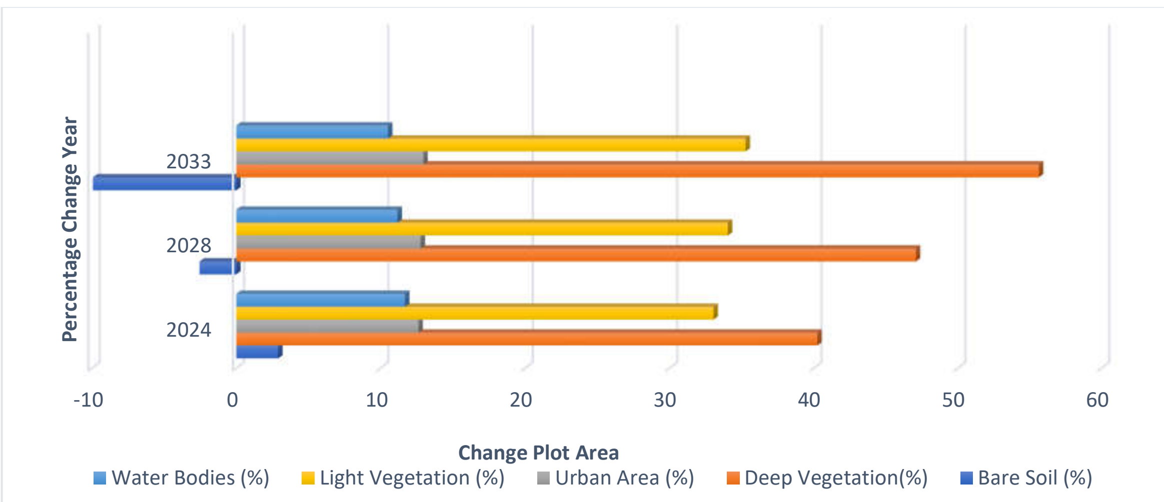

Fig. 10. Predicted change for 2024 to 2033

Table 7 presents the predicted data for the next 10 years (2024 to 2033) for average maximum temperature, average minimum temperature, and average precipitation. A linear extrapolation was used to forecast the average maximum temperature, average lowest temperature, and average precipitation over the following decade (2024÷2033), using 2003, 2013, and 2023 data (Fig. 11). The research suggests a gradual but continuous rise in the average maximum temperature, from 29.758°C in 2024 to 29.830°C in 2033.

Table 7. Predicted data for the next 10 years (2024 to 2033) for average maximum temperature, average minimum temperature, and average precipitation

Year	**Avg Max Temp (°C)**	**Avg Min Temp (°C)**	**Avg Precipitation (mm)**
2024	29.758	18.771	3.517
2025	29.766	18.712	3.644
2026	29.774	18.653	3.771
2027	29.782	18.594	3.898

Year	Avg Max Temp (°C)	Avg Min Temp (°C)	Avg Precipitation (mm)
2028	29.79	18.535	4.025
2029	29.798	18.476	4.152
2030	29.806	18.417	4.279
2031	29.814	18.358	4.406
2032	29.822	18.299	4.533
2033	29.83	18.240	4.660

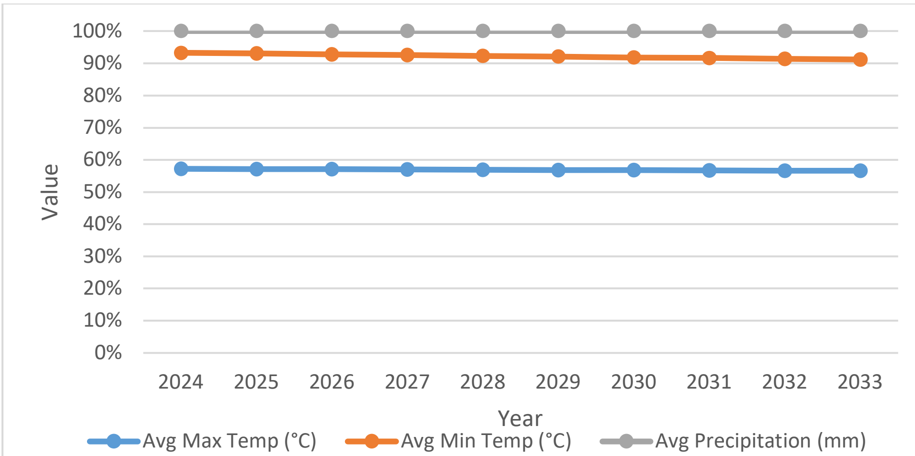

Fig. 11. Predicted climate trends (2024÷2033): average maximum temperature, average minimum temperature, and precipitation

Such a tendency might result in progressive warming of the region, impacting the local environment, agriculture, and overall climate. The average lowest temperature, on the other hand, is expected to fall slightly from 18.771°C in 2024 to 18.240°C in 2033, implying that the nighttime temperature would gradually reduce. The divergence of day and night temperatures may result in bigger temperature discrepancies. Furthermore, the average precipitation is expected to rise from 3.517 mm in 2024 to 4.660 mm in 2033, indicating a trend of increasing rainfall. This rise in precipitation would influence water resource management, flood risk mitigation, and agricultural planning. The anticipated trends may emphasize the significance of continual climate monitoring and adaptation plans for potential negative impacts on the environment and society.

DISCUSSIONS AND RECOMMENDATIONS

This study highlights significant LULC changes in Niamotpur Upazila from 2003 to 2023. The most notable transformations include a dramatic reduction in bare soil and a substantial increase in deep vegetation, reflecting positive ecological improvements. Bare soil decreased by 86.5%, and deep vegetation rose by 169%, suggesting successful land management efforts aimed at reducing degradation and enhancing reforestation.

Urban areas and light vegetation exhibited fluctuating trends, peaking in 2013 before declining by 2023. While this indicates progress in land conservation, it also points to the need for sustainable urban planning to balance development and environmental preservation [17].

Climatic factors have influenced these changes, with extreme drought-prone areas decreasing and no-risk areas increasing. Although temperature fluctuations were minor, the increase in precipitation likely contributed to the recovery of water bodies by 2023. The study suggests that, despite some stabilization in drought categories, climate variability remains a challenge for land management.

Looking ahead, projections for 2024÷2033 predict further increases in deep vegetation and a near disappearance of bare soil, underscoring the importance of continued sustainable land use practices. However, the anticipated decline in water bodies highlights the need for effective water management strategies.

In summary, this research provides valuable insights into LULC dynamics in Niamotpur Upazila and emphasizes the importance of integrating ecological restoration with climate adaptation. Future studies could benefit from higher-resolution data to capture more detailed land changes, aiding in better-informed policy decisions.

Due to rapid urbanization and population increase brought on by significant reductions in agricultural land, Bangladesh has experienced rapid land use and population change (LULC) [18]. Additionally, diachronic spatial and non-spatial investigations of changes in forest areas have discovered that LULC was carried out with various components across time [19]. Implement sustainable land use policies to deal with the decline in vacant land and the potential risk of extinction by 2033. This could lead to reduced agricultural productivity, sustainable agricultural practices, and land conservation schedules.

Human activities have a tremendous impact on the natural environment and ecosystem globally, particularly through changes in LULC [20]. Develop an urban planning framework that promotes the expected growth of the city while protecting existing green spaces and water bodies. This includes effective planning for public transport, infrastructure, and community development. Encourage afforestation and replanting to preserve deeper young vegetation. This will help mitigate climate change and preserve the natural balance. Implementing water management strategies, such as runoff, rainwater harvesting, and irrigation efficiency can help manage the gradual loss of water Prevent subsidence, and gradually eliminate it by implementing water management strategies, including rainwater harvesting and efficient irrigation. Develop climate change adaptation strategies to mitigate the effects of high temperatures, and precipitation changes on the environment and communities by communities through educational programs to share knowledge on the benefits of land use efficiency and conservation of natural resources. Encourage changes in Niamotpur Upazila governance and planning systems that encourage substandard development and conservation. Develop a process for tracking and testing the implementation of strategies, and making adjustments as needed in response to results.

CONCLUSIONS

The analysis of LULC changes in Niamotpur Upazila from 2003 to 2023 reveals significant shifts in the landscape. The most notable changes include a substantial decrease in bare soil and a considerable increase in deep vegetation. Urban areas and light vegetation peaked in 2014 but both saw reductions by 2023, while water bodies decreased initially but showed some recovery by 2023. These landscape changes are closely linked to vegetation health and drought conditions. Over the years, areas experiencing extreme drought have consistently decreased, while no-risk (NR) drought areas have significantly increased, indicating an overall improvement in vegetation health. Conversely, moderate and light drought categories increased substantially between 2003 and 2013; however, moderate drought areas continued to rise, while light drought areas decreased by 2023. The severe drought category experienced a moderate increase until 2013, followed by a decrease by 2023. Despite the valuable insights provided, this study has limitations primarily due to the 30-meter resolution of satellite imagery and reliance on free Landsat images, which may not capture small-scale characteristics accurately. Additionally, data collection outside the wet season may affect the assessment of urban greenery. Future studies can benefit from higher-resolution data collected year-round to provide a more comprehensive understanding of environmental dynamics. Overall, the study underscores the complex interplay of climate, land use, and human activity in Niamotpur Upazila. The findings highlight the need for higher-resolution data and year-round information to enhance landscape resilience and inform strategies against climate change, support sustainable development, and improve long-term environmental management.

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