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Spatiotemporal Dynamics of Land Use/Land Cover and Climate Variability in a Morphoclimatic Setting of Barlekha Upazila, Sylhet, Bangladesh

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ABSTRACT

Morphoclimatic systems are responsive to climatic fluctuations and human-induced land transformations, especially within rapidly urbanizing regions of South Asia. This study examines the spatiotemporal patterns of land use and land cover (LULC) change and related climatic variability in Barlekha Upazila, northeastern Bangladesh, from 2005 to 2021, focusing on their implications for morphoclimatic processes. Multi-temporal satellite images from 2005, 2010, 2015, and 2021 were analyzed using Geographic Information Systems (GIS) and remote sensing techniques. Major LULC categories—water bodies, vegetation, agricultural land, and built-up areas—were identified through an unsupervised classification method. Climatic parameters, including temperature, precipitation, and relative humidity, were obtained from NASA datasets to assess seasonal and interannual variations and their linkage with LULC dynamics.

The results reveal pronounced declines in natural land covers, with water bodies and vegetation decreasing by approximately 51% and 27%, respectively, over the study period. In contrast, built-up and agricultural areas expanded substantially, reflecting intensified urbanization and land conversion. These transformations have altered surface characteristics and hydrological processes. Climatic analysis shows consistent seasonal patterns alongside increasing temperatures and enhanced monsoon rainfall in recent years, indicating growing climatic variability and possible monsoon intensification. The combined LULC and climate trends demonstrate strong interactions between anthropogenic land-use changes and local climate dynamics. Overall, the findings highlight the increasing vulnerability of Barlekha's morphoclimatic systems to unplanned urban growth and climate change, emphasizing the need for climate-responsive urban planning and sustainable land management strategies to enhance long-term environmental resilience.

Keywords: Urbanization, Morphoclimatic, Anthropogenic Activities, Land Cover Land Use, and Groundwater Level

INTRODUCTION

Morphoclimatic zones are regions where landforms and surface processes are primarily controlled by prevailing climatic conditions, resulting in distinctive geomorphological characteristics that form over long-time scales (Singh et al., 2021). Climate plays a fundamental role in regulating morphoclimatic dynamics. Variations in rainfall intensity, temperature extremes, and seasonal patterns influence erosion rates, sediment transport, and landscape stability. Recent climate change has intensified these processes, leading to accelerated landform modification, increased surface runoff, and higher susceptibility to flooding and soil degradation in many regions (IPCC, 2021).

Urbanization is a primary driver of modern environmental shifts, profoundly altering land use and land cover (LULC) worldwide and with significant ecological and hydrological repercussions. It significantly alters morphoclimatic systems by modifying natural land surfaces and local climatic conditions. In rapidly expanding cities of developing regions, the surge in built-up impervious surfaces—driven by population growth, infrastructure expansion, and industrialization—comes at the cost of vegetation, wetlands, and permeable landscapes (Seto et al., 2012; Bikis et al., 2025). The expansion of impervious built-up areas disrupts natural drainage networks, reduces infiltration, and increases surface temperatures through urban heat-island effects (Li et al., 2022). These changes can amplify climate-driven geomorphic processes, such as erosion and land subsidence, thereby reshaping morphoclimatic zones. This conversion diminishes soil infiltration, boosts surface runoff, and curtails groundwater recharge, while escalating urban water demands amplify extraction rates, hastening aquifer depletion (Rahaman et al., 2020). These dynamics disrupt natural hydrological cycles, elevate local temperatures through the urban heat island effect, and strain ecosystem integrity (Nath et al., 2020; Scanlon et al., 2005). Consequently, urbanization acts as a key anthropogenic force that interacts with climate variability to transform landscape morphology, emphasizing the need for climate-sensitive urban planning and land management strategies.

Satellite imagery, coupled with GIS and remote sensing, enables precise spatiotemporal mapping of LULC transitions and investigates urbanization-induced environmental change and groundwater dynamics (Foster & Chilton, 2003). Such tools enable integrated assessments of how urban expansion modifies surface processes, energy balances, and water security. Multi-temporal satellite imagery enables accurate detection of land use and land cover (LULC) transitions, urban expansion patterns, and surface imperviousness at different spatial and temporal scales (Rahaman et al., 2020; Weng, 2012). Remote sensing (RS) and Geographic Information Systems (GIS) have proven essential for evaluating land-use and land-cover (LULC) changes driven by urbanization in Gazipur District, Bangladesh. Multi-temporal satellite imagery and spatial analysis reveal significant expansion of built-up areas at the expense of agricultural land, vegetation, and water bodies, reflecting rapid urban growth and transformation of natural landscapes (Raza et al., 2021). Additionally, this approach enhances the accuracy and efficiency of detecting spatiotemporal LULC dynamics, enabling detailed mapping of urban expansion and its environmental impacts (Akhi et al., 2021). These approaches support evidence-based urban planning and sustainable land management.

Land use and land cover (LULC) changes in Bangladesh, especially in critical wetland systems like Hakaluki Haor, have profound environmental and socio-ecological impacts. Over 23 years (2000–2023), the freshwater wetland experienced a marked ~51% reduction in water bodies and a ~71% decline in vegetation cover, signaling significant degradation of wetland functions and habitats. Concurrently, settlement areas expanded by about 353%, reflecting growing human encroachment and pressure on natural landscapes driven by population growth and land demand (Siddique et al., 2024). These spatiotemporal shifts disrupt freshwater availability, reduce support for biodiversity, and alter hydrological processes vital to flood regulation and groundwater recharge. The loss of wetlands and vegetation also compromises ecosystem services, such as flood control, climate regulation, and fisheries, affecting local livelihoods and resilience.

LULC changes in Bangladesh are driven by complex interactions between biophysical and socioeconomic factors at the national scale (Xu et al., 2020). During 2000–2010, significant conversions occurred between agricultural land, water bodies, forests, and shrubland, indicating dynamic landscape transformations across the country. While gross gains and losses in agricultural land were substantial locally, net change at the national level was minimal. However, forest loss, shrubland expansion, and conversions related to water bodies highlight region-specific impacts (Xu et al., 2020). Rapid urbanization in Bangladesh has driven significant spatiotemporal changes in land use and land cover (LULC) (Weng, 2022). Expansion of built-up areas has replaced natural surfaces such as vegetation, wetlands, and agricultural land, altering surface energy balance and increasing imperviousness. These changes contribute to higher surface temperatures, disrupted hydrological processes, reduced infiltration, and increased runoff.

Land-use and land-cover changes in Dhaka substantially degrade urban ecosystem services, reducing green spaces, biodiversity, and climate regulation. Expansion of built-up areas reduces ecosystem service value, increases environmental stress, and diminishes benefits such as air purification, flood mitigation, and recreational spaces, all of which are essential to urban sustainability (Rahman & Hossain, 2023).

Urban growth also intensifies environmental pressures by fragmenting habitats and degrading ecological functions. LULC transformations associated with urbanization exacerbate local climate impacts, elevate heat exposure, and strain water resources (Weng, 2020).

Urban growth in Bangladesh's northeastern region highlights the significant impacts of LULC changes on the urban ecosystem. Rapid expansion of built-up areas has reduced natural green spaces, agricultural lands, and wetlands, leading to habitat fragmentation and lowered ecological integrity. These transformations disrupt hydrological processes, increase surface runoff, and elevate risks of flooding and soil erosion. Loss of vegetation and permeable surfaces also contributes to higher urban temperatures and diminished air quality (Samad et al., 2023).

Urbanization-driven land use and land cover (LULC) change in Bangladesh significantly impacts ecosystems by altering surface processes, water dynamics, and habitat integrity, thereby modifying drainage patterns, increasing erosion potential, and disrupting watershed stability and soil conservation (Hassan et al., 2025). In Barlekha Upazila, urban expansion has transformed natural landscapes, reducing vegetation and water bodies while reshaping morphoclimatic characteristics, which affects local hydrology and ecological balance (Sharmin et al., 2025). Collectively, these changes diminish ecosystem services, escalate surface runoff and sediment transport, and degrade habitat quality. The cumulative effects underscore the need for integrated urban planning and sustainable land management to protect ecosystem functions amid rapid urban growth in Bangladesh.

This study examines rapid land-use and land-cover (LULC) changes in Borolekha, Maulovibazar, Sylhet division, Bangladesh. Rapid urbanization, intensive agriculture, and deforestation have environmental impacts, including increased flood risks and biodiversity loss. Anthropogenic transformations have altered surface properties, vegetation cover, and hydrological processes, influencing local environmental conditions and micro-climate, particularly temperature, rainfall variability, and humidity (Moniruzzaman et al., 2020; Rahman et al., 2022)

Study Area

Barlekha Upazila is located in Maulvibazar District in northeastern Bangladesh, covering an area of 315.58 km², bounded by 24°36′–24°50′ N and 90°01′–90°18′ E. Beanibazar borders it to the north, Juri to the south, Assam (India) to the east, and Kulaura, Golapganj, and Fenchuganj to the west, sharing an approximately 20-km international boundary with India (BBS, 2007; Figure 01). In recent decades, Barlekha has experienced significant land-use and land-cover changes driven by urban expansion, intensified agriculture, deforestation, and industrial activities.

METHODOLOGY

Geographic Information Systems (GIS) and remote sensing techniques were employed to assess the spatiotemporal dynamics of land use and land cover (LULC) and to examine their relationship with the reduction of surface water bodies, consistent with recent applications in environmental change studies (Weng, 2012; Lu et al., 2021). Multi-temporal satellite imagery for 2005, 2010, 2015, and 2021 was acquired from the United States Geological Survey (USGS) to facilitate consistent LULC interpretation and change detection over time (USGS, 2021). ArcGIS version 10.3 was used for image preprocessing, classification, and spatial analysis, including layer integration and area calculation. An unsupervised classification approach was applied to categorize imagery into distinct LULC classes, enabling objective differentiation of land cover types based on spectral signatures (Jensen, 2016). Climatic variables—temperature, precipitation, and relative humidity—were obtained from the NASA Data Access Viewer for 2005–2021 and analyzed to evaluate temporal variations and interactions with LULC changes and surface water reduction. Integrating spatial and climatic datasets provided a robust framework to assess how land transformation processes influence local environmental and climatic patterns in the study area (Lu et al., 2021; Weng, 2012; Figure 2; Table 1).

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RESULT AND DISCUSSION

LULC Changes

Unsupervised classification was conducted across four time points (2005, 2010, 2015, and 2021) to evaluate changes in water bodies, vegetation, agricultural land, and built-up areas in Barlekha Upazila. Results demonstrated apparent spatiotemporal shifts in land use and land cover (LULC) consistent with documented regional trends of urban expansion and natural land reduction. Water bodies experienced a marked decline from 827.388 sq km in 2005 to 406.071 sq km in 2021, while vegetation cover decreased from 1681.101 sq km to 1223.460 sq km over the same period. These declines reflect broader patterns observed in Bangladesh and similar rapidly developing contexts, where natural land cover shrinks under anthropogenic pressure (e.g., decreases in water bodies and vegetation accompanying urbanization), as documented in recent LULC research (Haque et al., 2025; Figure 3; Table 2).

Built-up areas increased significantly, rising from 974.961 sq km in 2005 to 1296.801 sq km by 2021, indicating rapid urban growth and land conversion. Agricultural land also expanded, from 371.196 sq km to 928.314 sq km, suggesting changes in land management and increasing cultivation intensity. Intermediate periods (2010 and 2015) showed transitional patterns with notable decreases in natural land covers and increases in built-up and agricultural areas, underscoring progressive landscape transformation. These findings mirror documented dynamics in other Bangladesh settings, where built-up expansion has contributed to the loss of agricultural, vegetation, and water resources over time.

Overall, the temporal LULC analysis highlights significant landscape alterations driven by urbanization and human activities, underscoring the need for sustainable land-use planning to mitigate environmental degradation and support ecological resilience.

Climate Changes

Monthly climate data for Barlekha Upazila across 2005, 2010, 2015, and 2021 reveal seasonal variability in temperature, rainfall, and relative humidity, consistent with broader regional trends in Bangladesh's climatic dynamics (Figure 4). Each year, temperatures at the 2-meter air level and surface (skin) conditions showed a gradual increase from January, reaching peak values between May and August before declining toward December. This pattern aligns with studies indicating rising maximum and minimum temperatures in Bangladesh over recent decades, especially during the pre-monsoon and monsoon seasons (Al-Munsur et al., 2025). Higher peak temperatures in 2015 and 2021 compared to 2005 suggest an ongoing warming trend, reflecting broader temperature increases documented in the Sylhet region and other parts of the country (Rahman et al., 2022; Al-Munsur et al., 2025).

Precipitation exhibited distinct seasonality, with minimal rainfall during the dry months (November–February) and pronounced monsoon rainfall from June to August, as expected in South Asian monsoon climates. Monsoon rainfall intensity in 2015 and 2021 was notably higher than in earlier periods, indicating increased variability in rainfall distribution and intensity, mirroring findings of shifting precipitation patterns in Bangladesh's monsoon regime (World Bank, 2021; Suhan & Adhikary, 2025). Relative humidity followed similar seasonal trends, remaining lower in dry months and peaking during the monsoon, consistent with moisture dynamics under enhanced monsoon influence (Figure 5).

Barlekha's climatic data show stable seasonal cycles, though with elevated temperatures and heavy monsoon rainfall in recent years. These trends point to increased climatic variability and the potential intensification of monsoon characteristics, with significant implications for local hydrology, agriculture, and water resources. Such patterns reflect broader regional climate shifts driven by global warming and changes in atmospheric circulation over South Asia.

Climatic analysis complements the LULC findings by revealing persistent seasonal patterns alongside emerging long-term changes. Rising surface and air temperatures, especially during the pre-monsoon and monsoon seasons, point to an ongoing warming trend in the region. Additionally, increased intensity and variability of monsoon rainfall in recent years suggest a potential intensification of monsoon characteristics. These climatic shifts, when coupled with declining vegetation and water bodies, may exacerbate flood risks, disrupt groundwater recharge processes, and pose challenges to agricultural sustainability (Khatun et al, 2022; Figure 6).

CONCLUSION

This study presents an integrated assessment of land use and land cover (LULC) change and climatic variability in Barlekha Upazila from 2005 to 2021, highlighting the combined influence of anthropogenic activities and evolving climate dynamics on the local environment. The unsupervised classification results reveal pronounced spatiotemporal transformations, characterized by a substantial decline in natural land covers, particularly water bodies and vegetation, alongside a marked expansion of built-up and agricultural areas. The reduction of water bodies from 827.388 sq km to 406.071 sq km, and the significant loss of vegetation cover, underscore the increasing environmental pressure resulting from rapid urban growth, land conversion, and intensified agricultural practices. These patterns mirror broader national trends in Bangladesh, where unmanaged urban expansion has contributed to the degradation of critical ecological resources.

The steady increase in built-up areas and the expansion of agricultural land reflect shifting land management priorities and growing human demand for housing, infrastructure, and food production. Transitional patterns observed during intermediate years further indicate progressive landscape transformation rather than abrupt change, emphasizing the cumulative nature of anthropogenic impacts. Such alterations have important implications for surface hydrology, biodiversity, and ecosystem services, particularly through reduced natural water storage, altered runoff regimes, and increased vulnerability to environmental hazards.

Climatic analysis supports the LULC results by showing stable seasonal cycles alongside emerging long-term shifts. Increasing surface and air temperatures, particularly during pre-monsoon and monsoon periods, indicate regional warming, while heightened intensity and variability of monsoon rainfall suggest monsoon strengthening, potentially increasing flood risk, groundwater stress, and agricultural vulnerability.

Overall, the combined evidence highlights a strong interaction between land surface changes and local climatic variability in Barlekha Upazila. The findings emphasize the urgent need for sustainable, climate-responsive land-use planning and resource management strategies to mitigate environmental degradation, safeguard natural ecosystems, and enhance long-term ecological and socio-economic resilience in the region.

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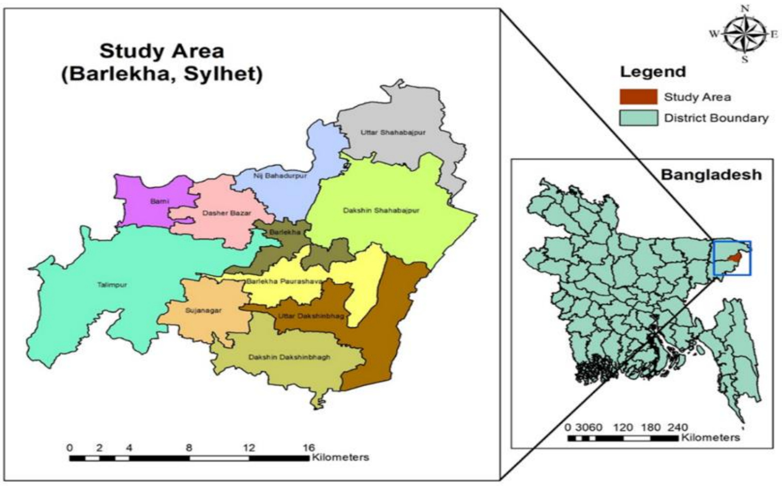


Figure 1: Map showing the location of the study area.

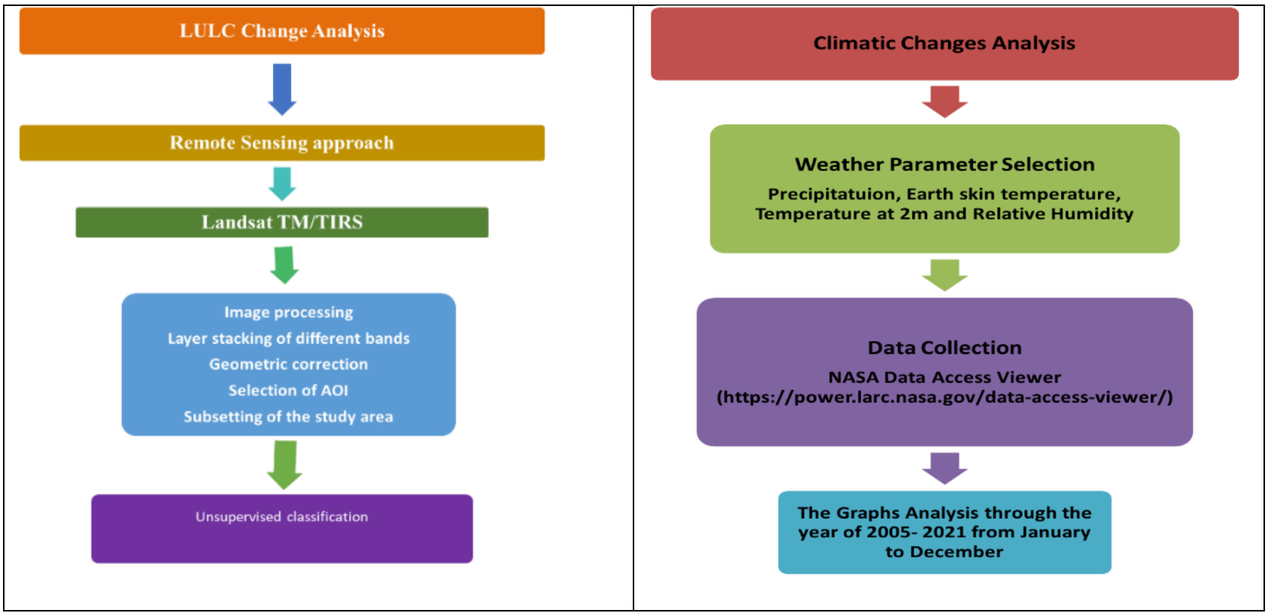
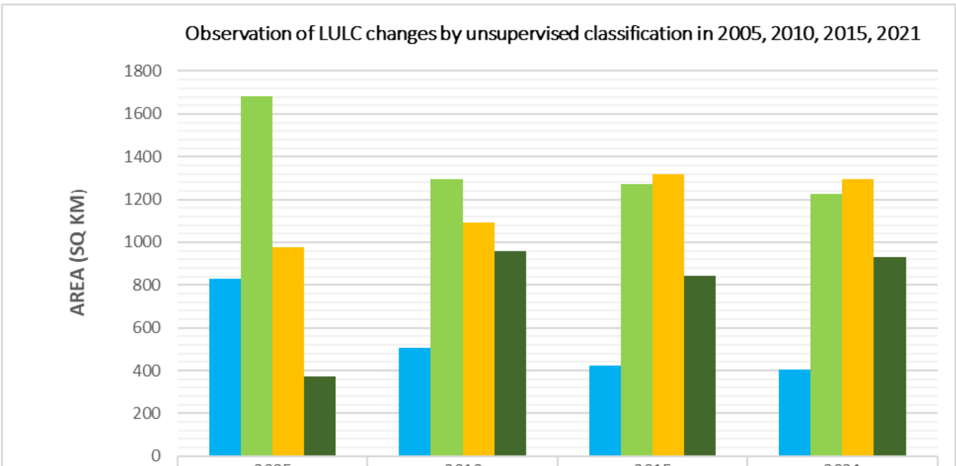


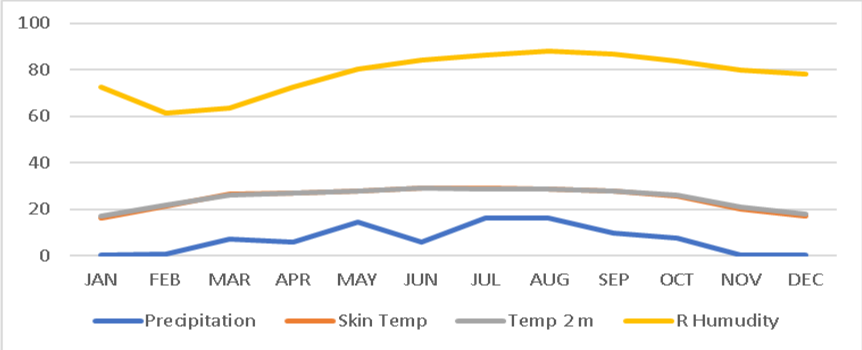
Figure 2: Methodology Chart.



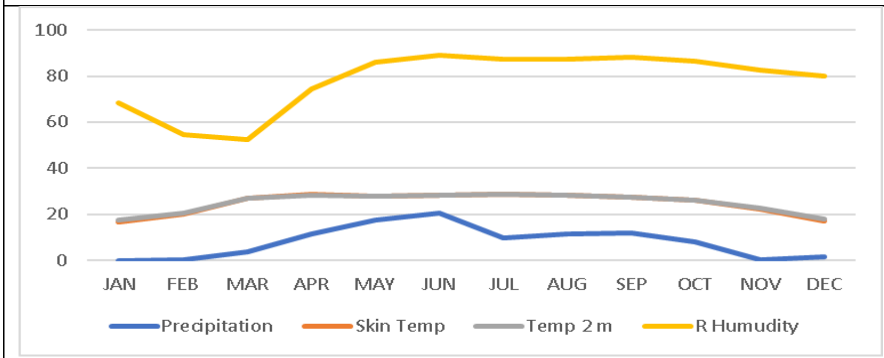
	2005	2010	2015	2021
Waterbody	827.388	504.072	425.331	406.071
Vegetation	1681.101	1297.053	1271.025	1223.46
Built up	974.961	1094.229	1317.024	1296.801
Agriculture land	371.196	959.292	841.266	928.314

Figure 3: Observation of LULC changes by unsupervised classification in 2025, 2010, 2015, and 2021.

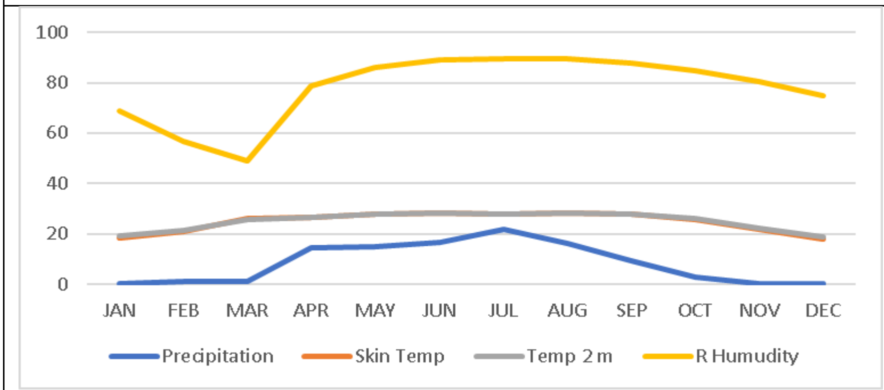
2005



2010



2015



2021

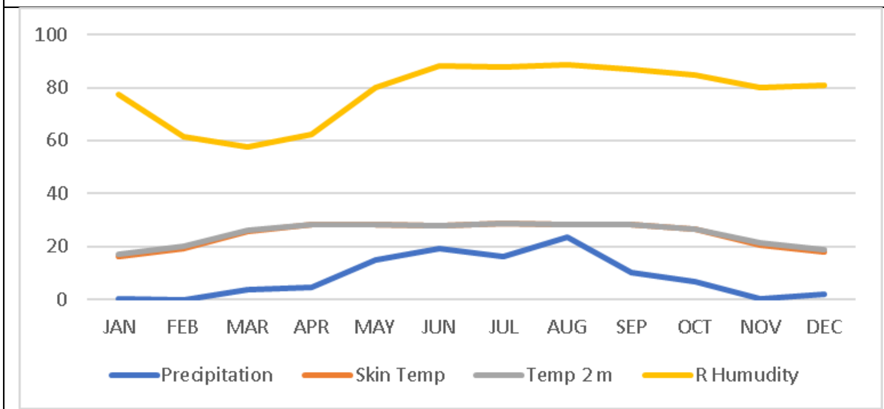


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Figure 4: Weather parameter data of Barlekha from 2005 to 2021.

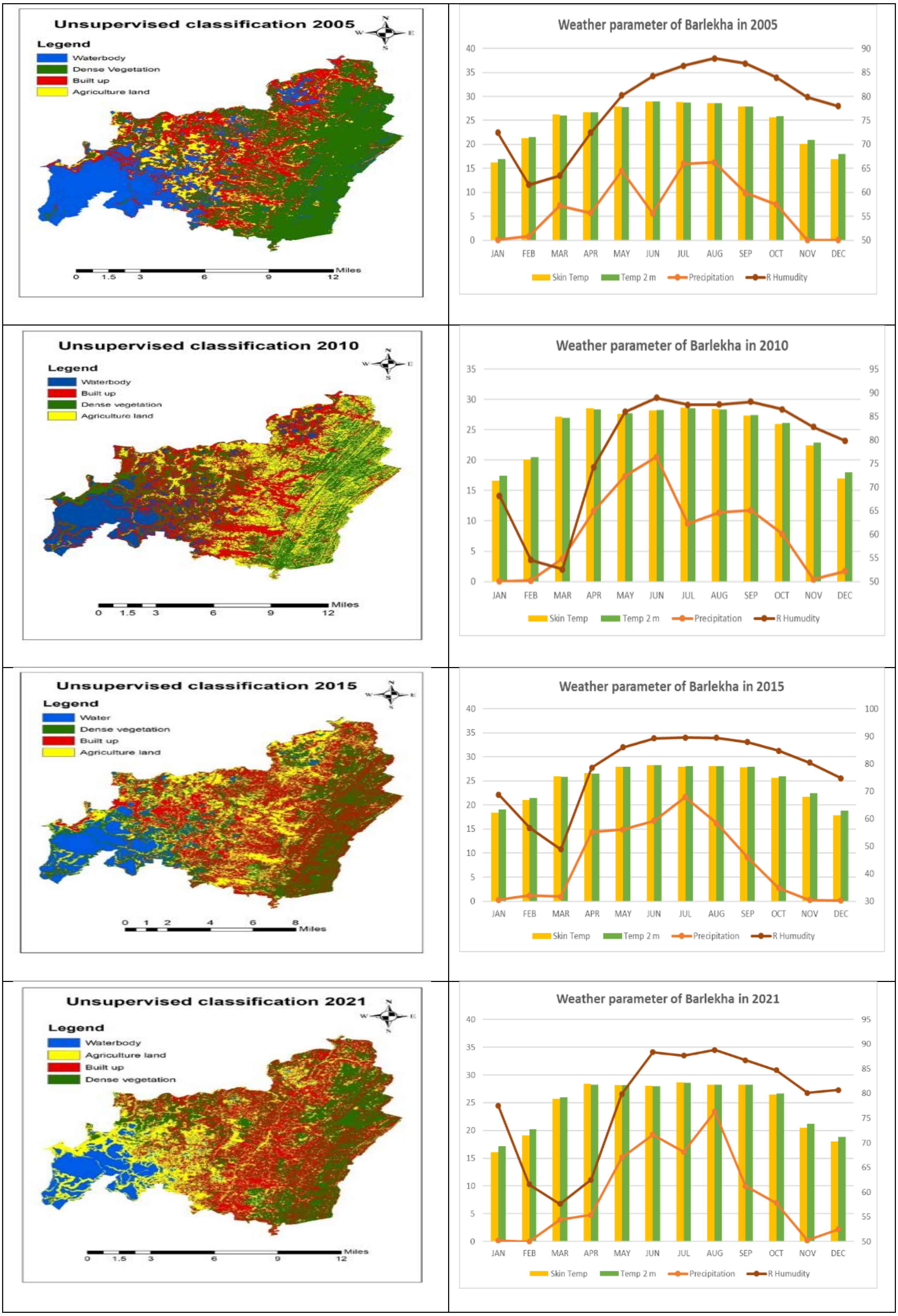

Figure 5: Comparative overview of LCLU and Climatic changes at Borlekha Upazila.

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Table 1: Satellite image specifications with their acquisition dates

Sensor platform	**Projection**	**Acquisition date**	**Resolution of used Bands**	**Path/ Raw**
Landsat 4-5 (TM)	UTM, Zone 46 WGS 84 UTM, Zone 46 WGS 84	25-11-2005 23-11-2010	30 30	137/44 137/44
Landsat 8 (OLI/TIRS)	UTM, Zone 46 WGS 84 UTM, Zone 46 WGS 84	15-11-2015 05-11-2021	30 30	137/43 137/43

Table 2: LULC Changes determination by Unsupervised Classification from 2005 to 2021

Year	2005	2010	2015	2021
Classes	**Area (sq km)**	**Area (sq km)**	**Area (sq km)**	**Area (sq km)**
Waterbody	827.388	504.072	425.331	406.071
Vegetation	1681.101	1297.053	1271.025	1223.46
Built up	974.961	1094.229	1317.024	1296.801
Agriculture land	371.196	959.292	841.266	928.314