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ORIGINAL ARTICLE

Monitoring LULC Dynamics and Landscape Pattern Analysis Using Landsat at Mongla and Surrounding Cities in Bangladesh

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ABSTRACT

This study presents a thorough analysis of the temporal dynamics in land use and land cover (LULC) within the Mongla Port and its adjacent regions in Bangladesh, spanning from 2018 to 2022 and utilizing Landsat 8 satellite imagery. A seven-category classification system, including water bodies, trees, flooded vegetation, crops, built-up areas, bare ground, and rangeland, facilitated a detailed exploration of changing landscape patterns. Over the study period, a 1.87% reduction in tree cover was observed, contrasting with consistent expansion in built-up areas, which increased by 2.42%. Noteworthy fluctuations in agricultural lands revealed a net decrease of 165.95 km^2, while water bodies experienced fluctuations, ultimately recording a net increase of 142.29 km^2. The robust accuracy assessment, with overall accuracy ranging from 86.7% to 88.8%, underscores the reliability of the classification process. This research holds significant implications, offering valuable insights into sustainable development, conservation strategies, and disaster preparedness in a region undergoing transformative changes due to port establishment, especially considering the inclusion of the ecologically critical Sundarbans in the study area.

1 Introduction

Land use and land cover (LULC) changes are widely acknowledged as significant drivers of environmental transformation on a global scale, exerting profound influences on socio-economic progress and environmental sustainability (Chen, 2002). These changes, characterized by shifts in the distribution and composition of land cover types, have far-reaching implications for ecosystem functioning, biodiversity, climate regulation, and human well-being (Galata, 2020; Jiang and Tian, 2010; Mallupattu and Reddy, 2013).

In rapidly developing regions like Bangladesh, the dynamics of LULC changes are particularly pronounced due to factors such as rapid population growth, urbanization, industrialization, and agricultural expansion (Chen and Zhang, 2017). As urban centers expand and infrastructure development accelerates, there is a corresponding increase in the conversion of natural habitats into built-up areas, agricultural lands, and other human-modified landscapes (Kafi et al., 2014). This transformation not only alters the physical landscape but also affects ecological processes, ecosystem services, and the livelihoods of local communities (Li, 2017; Seyam et al., 2023). The Mongla Port area, situated in the southwestern part of Bangladesh and serving as the second-largest seaport in the country, exemplifies the complex interplay between human activities and environmental dynamics (Ali and Rahman, 2023). Over the years, the port and its surrounding regions have experienced significant development pressures driven by economic growth, industrial expansion, and urbanization (Khondoker and Hasan, 2020). These development initiatives, while contributing to regional economic prosperity and infrastructure enhancement, have also led to notable changes in LULC patterns, raising concerns about environmental degradation, habitat loss, and ecosystem fragmentation.

Despite the growing recognition of the importance of understanding LULC dynamics for sustainable development and environmental management, there remains a gap in comprehensive studies that systematically analyze the drivers and impacts of these changes in the Mongla Port area. Existing research tends to focus on broader regional or national-scale assessments, overlooking the unique socio-ecological contexts and development trajectories of specific localities (Giri et al., 2005; Vivekananda et al., 2021). Therefore, there is a

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pressing need for localized studies that delve into the intricacies of LULC dynamics at finer spatial scales, considering the diverse socio-economic and environmental factors shaping land use decisions and outcomes. Against this backdrop, this study seeks to fill this gap by examining the LULC changes occurring in the Mongla Port area and neighboring cities. By utilizing advanced remote sensing and Geographic Information Systems (GIS) techniques, this research aims to provide insights into the drivers, patterns, and impacts of LULC changes in the region. Specifically, the study aims to identify the main drivers of LULC changes, assess their implications for ecosystem services, biodiversity, and human well-being, and inform strategies for sustainable land use planning and management.

By explicitly stating the research problem and the specific gap being addressed, this study aims to contribute to the existing body of knowledge on LULC dynamics in rapidly developing regions like the Mongla Port area. The findings of this research are expected to inform policy-making, land use planning, and development interventions aimed at promoting sustainable urbanization, environmental conservation, and resilient socio-economic development in the region.

2 Methodology

2.1 Study Area

Mongla is the second-largest seaport in Bangladesh. The study area’s latitude and longitude are 22.52 ° N, and 89.59 ° E as shown in Fig. 1(b). Additionally, the location of Bangladesh is shown in Fig. 1(a) where the marked portion is the area of this study. The research area encompasses eight upazilas. The upazilas of Bagerhat Zila are Bagerhat Sadar, Rampal, and Mongla. The upazilas of Khulna district are Dumuria, Batiaghata, Paikgacha, Dacope, and Koyra. The total land area comprises about 5,040 km^2.

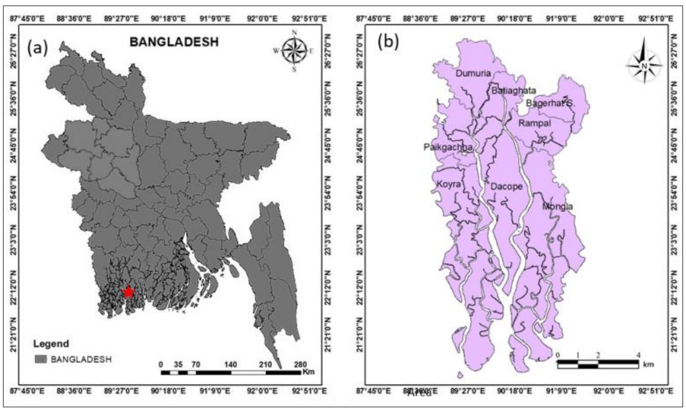

Fig. 1: (a) Location of a Mongla district in Bangladesh, and (b) map of the study area showing Mongla and surrounding cities.

2.2 Remote Sensing and Temperature Data

The search was conducted on the website of the United States Geological Survey to obtain remote sensing data specifically relevant to the years 2018, 2019, 2020, 2021, and 2022, as shown in Table 1. The data was collected under cloudless conditions; thus, no atmospheric correction was performed. The maps were geo-referenced to Universal Transverse Mercator (UTM) projection zone 46 N, which was determined based on the research area's position by the World Geodetic System (WGS)-1984 (Fayshal et al., 2023; Imran et al., 2021). The meteorological conditions collected from the Bangladesh Meteorological Department (BMD) are found in Table 1, which contains a tabulation of the Landsat band details as well.

Table 1: Landsat OLI/TIRS images used in this study.

Acquisition date	Satellite	Sensor	Path/row	Cloud cover (%)	Meteorological conditions
05 March, 2018	Landsat 8	OLI/ TIRS	137/44	<10%	Mean air temp. = 29 °C
					Humidity = 47%
					Rainfall = 0 mm
					Wind speed = 1.22 m/s
13 April, 2019	Landsat 8	OLI/ TIRS	137/44	<10%	Mean air temp. = 27.2 °C
					Humidity = 37%
					Rainfall = 0 mm
					Wind speed = 1.43 m/s
07 April, 2020	Landsat 8	OLI/ TIRS	137/44	<10%	Mean air temp. = 26.8 °C
					Humidity = 56%
					Rainfall = 0 mm
					Wind speed = 1.81 m/s
19 March, 2021	Landsat 8	OLI/ TIRS	137/44	<10%	Mean air temp. = 32.3 °C
					Humidity = 39.5%
					Rainfall = 0 mm
					Wind speed = 1.12 m/s
09 March, 2022	Landsat 8	OLI/ TIRS	137/44	<10%	Mean air temp. = 26 °C
					Humidity = 43.9%
					Rainfall = 0 mm
					Wind speed = 1.62 m/s

Methods of Land Cover Classification

2.2.1 Land Cover Classification

The classification method covers a range of LULC categories, including waterbodies, trees, flooded vegetation, crops, built-up areas, bare soil, and rangeland. Details of classification have been presented in Table 2.

Table 2: Details of land cover class.

Land Cover Type	Description
Waterbody	River, permanent open water, lakes, ponds, canals, low-lying areas permanent/seasonal wetlands, marshy land, and swamps
Trees	Tree cover, parks, forests, streets, and more.
Flooded vegetation	Grassland, vegetated lands, agricultural lands, and crop fields, as well as trees, natural vegetation, mixed forest, gardens, parks, and playgrounds
Crops	Cultivated areas of land dedicated to the growth of various agricultural plants, including grains, vegetables, fruits, and more
Built-up area	Residential, commercial, mixed-use, and industrial districts, villages, road networks, pavements, and man-made structures are all part of the infrastructure
Bare soil	Construction sites, developed land, excavation sites, open space, bare soils, and other land cover types include fallow land, earth, and sand land in-filling, construction sites, developed land, excavation sites, open space, bare soils, and the remaining land cover types
Rangeland	Open terrain that is typically characterized by natural grasslands, shrubs, and minimal tree cover

2.2.2 Accuracy Assessment of Land Cover Map

Accuracy evaluation is a crucial stage in image processing, particularly in detecting changes in LULC. Traditionally, these evaluations have been conducted by utilizing ground-truth data or by comparing with specific points from previously classified information (Arifeen et al., 2021). Kappa-based indices and overall accuracy are commonly used to evaluate the accuracy and determine the validity of classification algorithms (Chowdhury and Hafsa, 2022). This is shown in a matrix table displaying four distinct categories of accuracies. Accuracy assessment requires the collection of a sufficient number of samples for each map class, which are then compared to the true ground conditions (Congalton, 1991). The Kappa coefficient is commonly computed using a confusion matrix to accurately represent the accuracy of land cover mapping. The Kappa indices employed in this study comprise Producer Accuracy, User Accuracy, Overall Accuracy, and Kappa Coefficient. Producer accuracy quantifies the number of correctly identified positive values for a specific class, while user accuracy quantifies the number of incorrectly identified negative values for that class. Overall accuracy quantifies the number of correctly identified positive values for the entire thematic map (Das et al., 2021; Petropoulos et al., 2015).

To complete this task for the years 2018, 2019, 2020, 2021, and 2022, a total of 100 sampling points were generated from Google Earth. To evaluate the correctness of the LULC map for the years 2018, 2019, 2020, 2021, and 2022 and verify its accuracy, Google Earth was employed as a tool for confirmation (Hassan and Southworth, 2017). Currently, Google Earth is a highly valuable and widespread tool, and numerous researchers recommend it as a method of verification (Arifeen et al., 2021). The accuracy assessment utilized the following formulas:

$$Overall\ Accuracy = \frac{Total\ number\ of\ correctly\ classified\ pixels}{Total\ Sample\ Pixel} * 100 \quad (1)$$

$$User\ Accuracy = \frac{Number\ of\ correctly\ classified\ pixels}{Total\ number\ of\ classified\ pixels\ (Row\ total)} * 100 \quad (2)$$

$$Producer\ Accuracy = \frac{Number\ of\ correctly\ classified\ pixels}{Total\ number\ of\ classified\ pixels\ (Coloumn\ total)} * 100 \quad (3)$$

$$Kappa\ Coefficient = \frac{(Total\ Sample*Total\ Corrected\ Sample) - \sum(Coloumn\ Total*Row\ Total)}{TS^2 - \sum(Coloumn\ Total*Row\ Total)} * 100 \quad (4)$$

3 Results and Findings

3.1 Land Cover Changes

LULCs in the study area were put into seven groups based on time series Landsat images: water bodies, trees, flooded vegetation, crops, built-up areas, bare ground, and rangeland. The study area covered a total of 5539 km². The supervised classification was performed using the data collected in 2018, 2019, 2020, 2021 and 2022. The spatial distribution of these categories is illustrated in Fig. 2.

In 2018, the largest category of LULC was trees, which accounted for 3,028 km² of the total allocated LULC categories. It occupied almost 54.66% of the study area as shown in Fig. 3. The crops cover was 1,341 km² and occupied almost 24.22% of the area. The water body cover was 842 km² and accounted for approximately 15.20% of the study area. The built-up area occupied 225 km², representing around 4.06% of the total area. Detailed statistical summary of LULC in Mongla port and its surroundings for the period 2018-2022 has been illustrated in Table 3. The remaining land cover categories, including flooded vegetation, bare ground, and rangeland, make up a small percentage of the overall LULC in the study area. In 2019, trees covered a maximum area of 2,985 km², followed by cropland with 1,148 km². The water bodies covered an area of 1,016 km². The other land covers included flooded vegetation with 79 km², built-up area with 288 km², bare ground with 5 km², and rangeland with 19 km². In 2020, the trees covered 22,998 km² accounting for 54.12% of the total area. The other land covers accounted for the remaining 45.88%. The water bodies covered 1,127 km², flooded vegetation covered 78 km², crops covered 983 km², built-up area covered 326 km², bare ground covered 5 km², and rangeland covered 23 km².

The maximum land cover type is trees, accounting for 53.37%, followed by water bodies accounting for 19.67%. The cropland covers 18.94% of the total area, while the built-up area covers 6.02%. The flooded vegetation, bare ground, and rangeland account for 1.43%, 0.08%, and 0.49% respectively in 2021. In 2022, the land cover type of trees continues to dominate, accounting for 52.79% of the total area. Crops maintain their position as the second-largest land cover type, representing 21.22%. The water body coverage remains relatively stable at 17.77%, while the built-up area slightly increases to 6.48%. The percentages of flooded vegetation, bare ground, and rangeland in 2022 are recorded as 1.41%, 0.08%, and 0.24%.

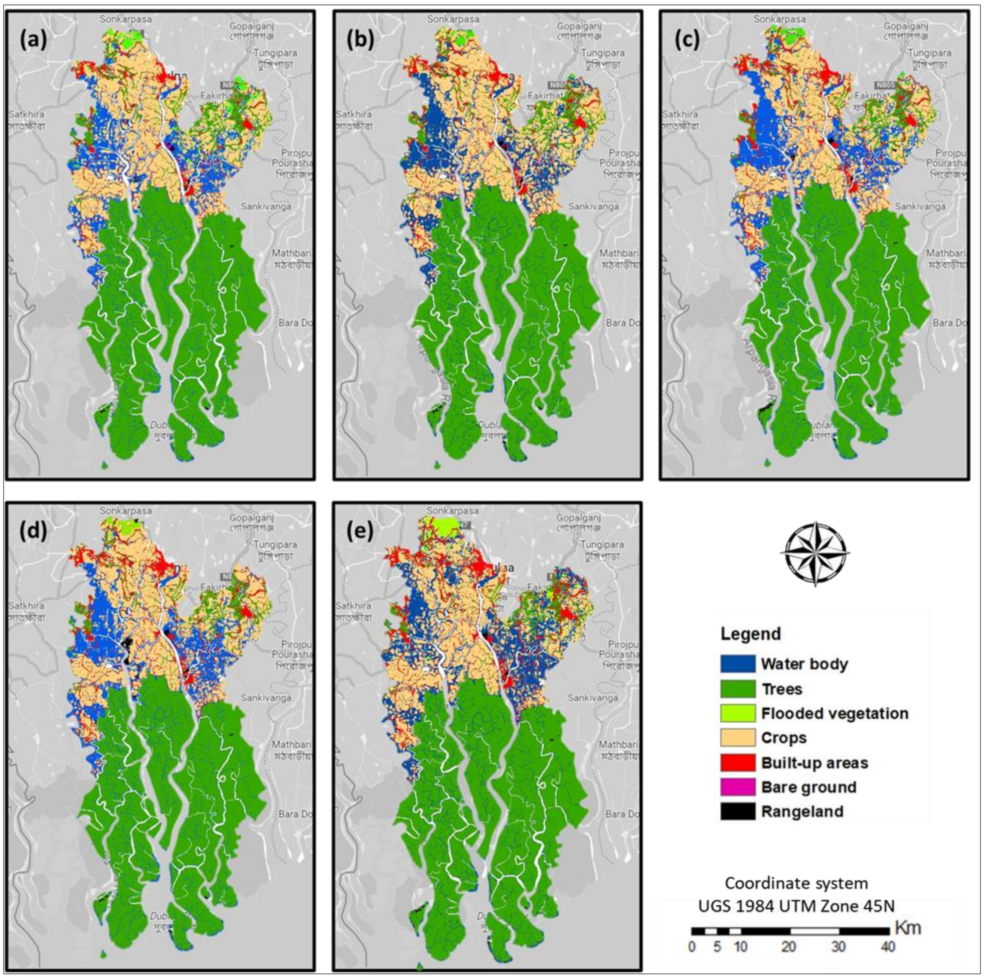

Fig. 2: Land cover map of Mongla and surrounding cities.

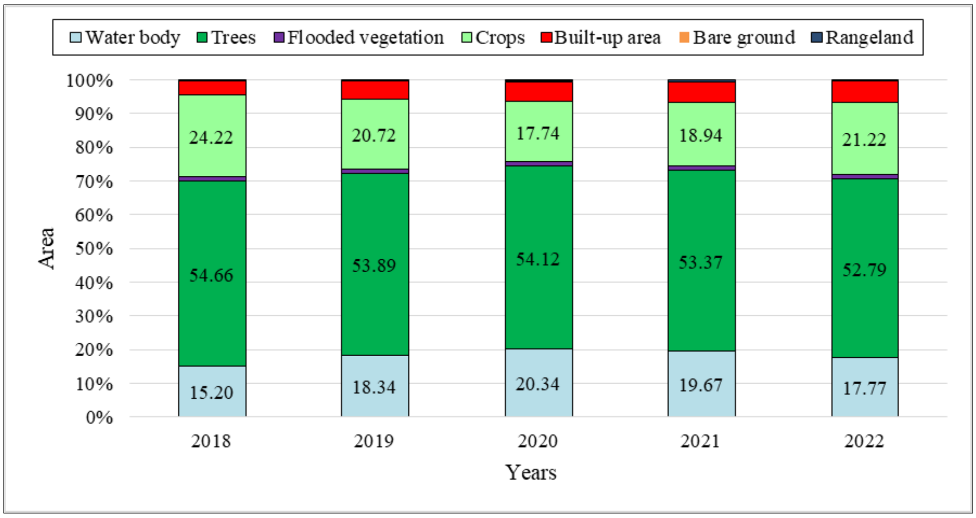

Fig. 3: Land cover percentages at Mongla port and its surrounding area during various time intervals.

Table 3: Statistical summary of LULC in Mongla port and its surroundings (2018–2022).

Years	2018	2019	2020	2021	2022
LULC (Area)	Area (km²)	Area (km²)	Area (km²)	Area (km²)	Area (km²)
Waterbody	842	1016	1127	1089	984
Trees	3028	2985	2998	2956	2924
Flooded vegetation	78	79	78	79	78
Crops	1341	1148	983	1049	1176
Built-up area	225	288	326	333	359
Bare ground	8	5	5	5	5
Rangeland	17	19	23	27	14
Total area	5540 km²				

3.2 Accuracy Assessment

The classification's accuracy was evaluated using multiple metrics, such as producer and user accuracies derived from the confusion matrix, total accuracy values, and kappa values.

Table 4: Accuracy of land cover analysis.

Category	2018	2019	2020	2021	2022
User's accuracy (%)					
Waterbody	97.8	93.2	92.1	91.5	91.4
Trees	77	77.2	83.4	85.1	79.1
Flooded vegetation	90.3	93.8	89.9	92.3	93.7
Crops	87	89.1	89.6	88	91.2
Built-up area	91.2	85.3	92	89.5	92
Bare ground	85.6	88.8	91.7	84.8	85.6
Rangeland	77.3	82.1	83	79.7	78.2
Producer's accuracy (%)					
Water body	91	92.2	94.7	89.1	92.1
Trees	82.1	79.9	81.7	89.1	84.4
Flooded vegetation	94.5	92.3	91.4	95.4	89.7
Crops	86.2	92.2	93	85.6	94.2
Built-up area	87.6	88.8	90.9	91.2	93.4
Bare ground	88	89.4	91.2	95.6	87.1
Rangeland	84.5	80.7	81.1	86.4	81.9
Overall accuracy (%)					
	86.7	87.1	88.8	87.3	87.3
Kappa coefficient					
	0.86	0.85	0.91	0.93	0.88

The classified maps for the years 2018, 2019, 2020, 2021, and 2022 had an overall accuracy of 86.7%, 87.1%, 88.8%, 87.3%, and 87.3% with a kappa coefficient of 0.86, 0.85, 0.91, 0.93 and 0.88 respectively (Table 4).

In the years 2018, 2019, 2020, 2021, and 2022, the user accuracy exceeded 75% and the producer accuracy exceeded 80%.

3.3 Changes in Land Cover Areas

The proportions of land cover surrounding Mongla Port at various time intervals have been presented in Table 5. The total increase in the water body area is 142.29 km². During the first one-year period, the water body experienced a 3.14% rise in size, reaching a total of 174.11 km². In 2020, there was a 2% increase, resulting in an area of 110.77 km². However, in 2021 and 2022, the area declined by 0.67% and 1.0% respectively. In the year from 2018 to 2019, there was a 0.77% decline in the total land area occupied by trees, which amounted to a decrease of 42.81 km². In the subsequent year, 2019-2020, there was a marginal 0.23% growth, resulting in the addition of 12.74 km²of tree cover. Yet, from 2020 through 2021, there was a significant decrease of 0.75%, resulting in a reduction of 41.54 km². In the 2021-2022 year, the trend persisted with a further reduction of 0.58%, resulting in a decline of 31.96 km². From 2018 to 2022, the total tree cover decreased by 1.87%, equivalent to a reduction of 103.56 km².

Moreover, the variations in LULC changes observed in Mongla Port and its neighboring areas from 2018 to 2022 are expressed as differences in area percentages in Fig. 4. There was a negligible amount of alteration in the flooded vegetation over this period. In the period from 2018 to 2019, there was a marginal rise of 0.02% in the area, equivalent to 0.27 km². From 2019 to 2020, there was a minor loss of 0.01%, leading to a reduction of 0.55 km². From 2020 to 2021, the extent of flooded vegetation expanded by 0.02%, resulting in an additional 1.11 km²of flooded vegetation. However, throughout the year 2021-2022, there was a decrease of 0.02%, resulting in a reduction of 1.25 km². From 2018 to 2022, there was a slight decrease of 0.01% in the total area, which corresponds to a decline of 0.42 km². From 2018 to 2022, there was a 3.00% decrease in the total agricultural area, which corresponds to a decrease of 165.95 km². The agricultural area experienced a significant decrease of 3.50%, equivalent to a reduction of 193.83 km², from 2018 to 2019. In the 2019-2020 period, there was a further decrease of 2.98%, amounting to a reduction of 165.05 km². During the year 2020-2021, there was a significant growth of 1.20% in the total cultivated land, amounting to an additional 66.46 km². In the 2021-2022 period, there was a consistent upward trend, with a 2.28% growth, leading to the expansion of an extra 126.47 km²of agricultural land.

Table 5: Land cover percentages in the vicinity of Mongla port at different time intervals (2018-2022).

Year	2018-2019		2019-2020		2020-2021		2021-2022		2018-2022	
LULC Change	Area (km²)	%	Area (km²)	%	Area (km²)	%	Area (km²)	%	Area (km²)	%
Water body	174.11	3.14	110.77	2.00	-37.11	-0.67	-105.48	-1.90	142.29	2.57
Trees	-42.81	-0.77	12.74	0.23	-41.54	-0.75	-31.96	-0.58	-103.56	-1.87
Flooded vegetation	0.27	0.02	-0.55	-0.01	1.11	0.02	-1.25	-0.02	-0.42	-0.01
Crops	-193.83	-3.50	-165.05	-2.98	66.46	1.20	126.47	2.28	-165.95	-3.00
Built-up area	63.31	1.14	38.22	0.69	7.20	0.13	25.56	0.46	134.29	2.42
Bare ground	-2.86	-0.05	0.00	0.00	0.00	0.00	0.00	0.00	-2.86	-0.05
Rangeland	2.05	0.04	3.88	0.07	3.88	0.07	-13.59	-0.25	-3.78	-0.07

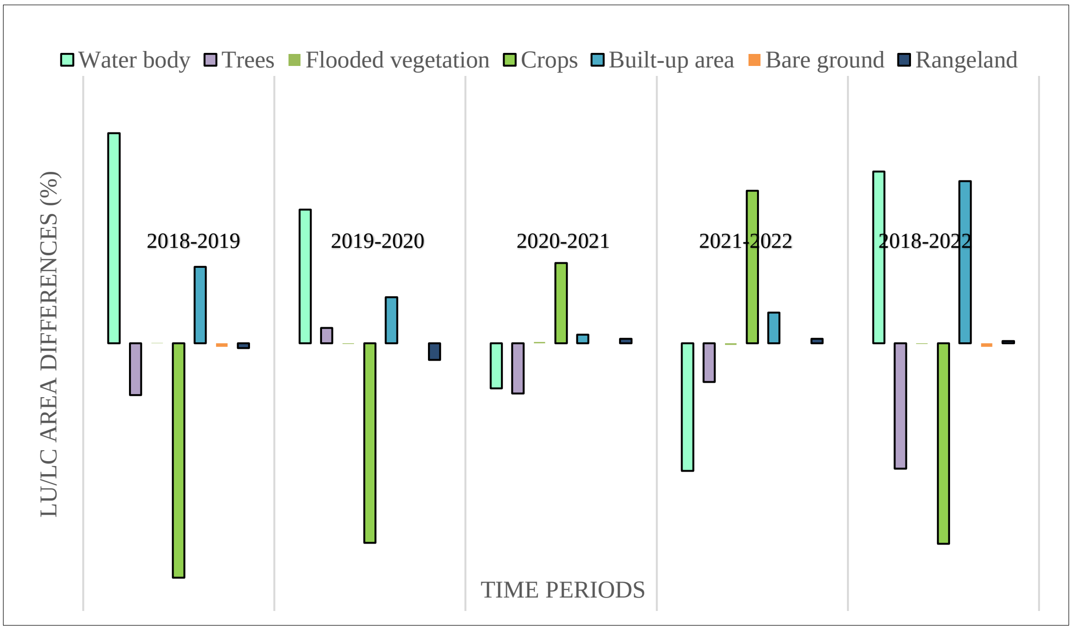

Fig. 4: Descriptions of LULC change in different periods in Mongla port and its surroundings from 2018 to 2022: difference of area (%).

The built-up area category experienced consistent expansion over this period. From 2018 to 2019, there was a 1.14% growth, resulting in the addition of 63.31 km². The rise persisted in 2019-2020, with a 0.69% growth, leading to the acquisition of an extra 38.22 km². From 2020 to 2021, there was a modest growth of 0.13%, resulting in an additional 7.20 km². In the years 2021-2022, the trend continued with a 0.46% rise, resulting in an extra 25.56 km²of developed land. Between 2018 and 2022, the total area of urban increased by 2.42%, equivalent to 134.29 km². There was a slight 0.05% decrease in bare ground during 2018-2019, resulting in a reduction of 2.86 km². However, there were no significant changes in 2019-2020, 2020-2021, or 2021-2022, leading to no net change in the cumulative period of 2018-2022. From 2018 to 2019, there was a marginal 0.04% expansion in rangeland, resulting in the addition of 2.05 km². In the subsequent year, 2019-2020, there was a marginal growth of 0.07%, resulting in an extra 3.88 km²of rangeland. The growth persisted in 2020-2021, exhibiting an additional 0.07% increase, resulting in the addition of 3.88 km². However, during the year 2021-2022, there was a reduction of 0.25%, leading to a decline of 13.59 km². Overall, from 2018 to 2022, there was a 0.07% decline, resulting in a reduction of 3.78 km²of rangeland.

4 Discussions

The observed changes in land cover areas within the Mongla port and its surroundings present intriguing insights into the evolving dynamics of the region's landscape. The consistent dominance of trees, albeit with a declining trend, raises questions about potential environmental implications. The reduction in tree cover by 1.87% over the studied period might be indicative of deforestation or changes in vegetation patterns, necessitating further investigation into the drivers behind such alterations. The agricultural landscape, as reflected in the crops category, exhibits a notable shift. While there is an overall decrease of 3.00% in the total agricultural area from 2018 to 2022, the individual yearly variations suggest nuanced patterns. The significant decrease of 3.50% in 2018-2019 is intriguing, potentially signaling changes in land-use practices, agricultural policies, or environmental factors influencing crop cultivation. Conversely, the subsequent years show a rebound, with a 2.28% growth in 2021-2022, emphasizing the dynamic nature of agricultural activities in the region.

Urban expansion, as indicated by the growth in the built-up area, raises concerns about the potential impacts on the local environment and ecosystems. The 2.42% increase in urban areas from 2018 to 2022 underscores the ongoing urbanization trend. Understanding the implications of such growth, including its effects on local biodiversity, water resources, and air quality, is crucial for sustainable urban development planning. The fluctuations in water body coverage, with both growth and decline observed over the years, suggest dynamic hydrological patterns. Investigating the factors influencing these changes, such as climate variability, human activities, or infrastructural developments, can provide valuable insights into the region's environmental resilience and vulnerability. The study's high accuracy, as indicated by overall accuracy values exceeding 86% and robust kappa coefficients, enhances the reliability of the findings. This suggests that the GIS-based classification methodology is a powerful tool for monitoring and assessing land cover changes over time. In summary, the comprehensive analysis of land cover changes in the Mongla port area provides a foundation for further research and environmental management initiatives. Understanding the drivers behind these changes is essential for developing sustainable strategies that balance human development with ecological conservation in this dynamic and evolving landscape.

While our study provides valuable insights into land cover changes within the Mongla port area, it is important to acknowledge certain limitations. Firstly, the scope of our analysis is constrained by the availability of recent data, which may not capture long-term trends or historical context. This limitation could impact the comprehensiveness of our findings and the ability to identify underlying drivers of land cover changes. Additionally, our reliance on remote sensing data and GIS-based classification methodologies introduces inherent uncertainties and potential inaccuracies, especially in areas with complex land cover patterns or limited ground truth validation. Furthermore, while our study highlights potential factors driving land cover changes such as deforestation, agricultural practices, and urbanization, the lack of detailed investigation into these factors represents another limitation. Future research should address these limitations to provide a more comprehensive understanding of land cover dynamics and inform effective environmental management strategies.

5 Conclusions

This study involved accomplishing a LULC change analysis of the Mongla Port and its surrounding cities in Bangladesh. The classification of satellite images encompassed seven distinct LULC classifications, including water bodies, trees, flooded vegetation, crops, built-up areas, bare ground, and rangeland. Over the study period spanning from 2018 to 2022, notable changes were observed in the LULC categories. Specifically, there was a discernible increase in water body and built-up areas by 142.29 km^2 and 134.29 km^2, respectively. Concurrently, there was a decline in tree cover and agricultural land by 103.56 $km^2$and 165.95 km^2, indicating dynamic shifts in land use patterns. The inclusion of the ecologically vital Sundarbans in the study area adds significant relevance to our findings. The Sundarbans, a UNESCO World Heritage Site, is renowned for its rich biodiversity and serves as a critical habitat for numerous species, including the endangered Bengal tiger. By examining land use changes in this context, our study offers valuable insights into the complex interplay between industrial activities, urban expansion, and the delicate Sundarbans ecosystem. Moreover, our research underscores the importance of sustainable development, conservation efforts, and disaster preparedness in the face of significant transformations induced by the establishment of the Mongla Port. By focusing specifically on the port, our findings shed light on the multifaceted challenges and opportunities inherent in managing a landscape characterized by industrial operations, urban growth, and environmental conservation priorities. Moving forward, it is imperative to delve deeper into the drivers behind these observed changes to formulate effective and sustainable strategies. This entails not only addressing immediate land use concerns but also considering broader environmental, social, and economic implications. Through interdisciplinary collaboration, stakeholder engagement, and robust research endeavors, we can pave the way for inclusive and environmentally conscious development in the Mongla Port region, ensuring the preservation of its natural heritage while fostering socio-economic progress.

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Author Contributions

Conceptualization M.A.F, methodology M.A.F; data analysis M.A.F, S.S, B.Z.; original draft preparation S.S, B.Z, M.A.F.; and writing - review, and editing, M.A.F. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare no conflict of interest..

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