Spatial Changes of Land Use Land Cover in Selected Islands of the Chattogram Coastal Belt

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Abstract. The study presents the spatial changes, i.e., LULC and temporal changes., Area and Bank Side change of four islands of Bangladesh- Nijhum Dwip, Kutubdia Island, Hatiya Island, and Sawndip from 1988 to 2024. In this study, the geospatial tools of The United States Geological Survey (USGS), Geographical Information System (ArcGIS 10.8), and Google Earth Pro (GEP) were used to examine the land loss, land cover changes and land use of the four aforementioned islands. In addition, the land cover classes identified in this study include agriculture, vegetation, water body, and bare land for Nijhum Dwip and Hatiya Island; plantation, salt pan, water body, bare land, and mangrove forest for Kutubdia Island; and agriculture, vegetation, water body, bare land, and mangrove forest for Sawndip Island based on physical properties through analysis of GIS from 1988 to 2024. Then, the quantification of change in each of the classes over 36 years was done. The data used in this land cover change detection analysis includes Landsat 5 Thematic Mapper (TM), Landsat 8 OLI, Landsat 9 OLI, and Thermal Infrared Sensor-TIRs. Therefore, this research has great significance concerning the potential impact, mainly because it thoroughly explains the changes within a substantial period in land use and cover. In that regard, it is notable that three of the four islands, except for Kutubdia, are situated in the Meghna River estuary. These islands have reported continuous changes because of constant erosion and accretion. It was found that the total land area of the studied islands except Sawndip fluctuates, but it increased in Sawndip. On the other hand, the size of Kutubdia has decreased.

Keywords: Temporal variation, Land classification, GIS, Island, Land Use Land Cover (LULC).

1 Introduction

Land use and land cover (LULC) show the condition of the Earth at a global scale, representing current and past surface features. Land cover may be defined as biophysical properties of the earth's surface, such as soil, vegetation, and water. In contrast, land use is how people utilize such resources in agriculture, housing, and industrial activities. Changes in land cover, driven mainly by human activities, have significant environmental consequences [1]. Although distinct, these concepts (LULC) are often

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interchangeable. Land use and land cover are dynamic and provide a proper understanding of the relationship and interaction between human activities and climate [2]. Bangladesh has a 710-km coastline with the Bay of Bengal in the Bengal Delta, South Asia. It houses 160 million people. About 45 million people (28% of the population) live in coastal areas less than 3 meters above sea level [3]. This coastal region is highly dependent on natural resources, accounting for 32% of Bangladesh's population. A major concern beyond the direct effects of cyclones and other natural hazards is land use and land cover changes that often occur after a catastrophic storm. Rising sea levels and erosion threaten Bangladesh's coastal areas. Studies predict that more than one million people in the Ganges-Brahmaputra-Meghna delta will be directly affected by sea level rise by 2025 [3]. Unsustainable LULC changes caused by natural hazards and human activities threaten biodiversity and ecosystem health. In coastal areas, soil degradation has been highly affected by unplanned land use and saltwater intrusion. The relationship of LULC changes with natural disasters has been highlighted in several studies, hence indicating the need for sustainable land use to reduce risks and protect ecosystems. However, the need cannot be more pressing. Land use and land cover change may accelerate natural and human-induced effects on the capacity of ecosystems to deliver services like biodiversity, natural resources, and water to the present and future human society. LULC mapping is one of the major components in the management of coastal vulnerability, as it aids in the identification of stable areas, thus enabling proper judgment for sustainable development and mitigating risks related to flooding and erosion hazards. Remote Sensing (RS) and Geographic Information System (GIS) techniques have become powerful tools for resource management and planning, providing spatial and statistical information for LULC analysis [1]. It is also beneficial for change detection, a method of analyzing changes in the state of an entity or event over time, especially for LULC monitoring. RS and GIS technologies have proven helpful in generating information on forest cover, vegetation, and land use, particularly in tropical regions. Land surveys, current maps, statistical data, existing documents or accessible literature, Landsat images, and remote sensing images serve as some of the data resources for land cover change and analysis. However, developing countries like Bangladesh face several challenges due to limited access to geospatial datasets and cannot keep pace with LULC changes. However, with the advancement in geospatial technology, the efficiency of LULC mapping at the landscape level has dramatically improved. This study assessed four islands – Nijhum Island, Hatiya Island, Sawndip, and Kutubdia Island. The Geographic Information System (GIS) method is used to study the morphological conditions of the given four islands and to get other descriptive information required for proper land use planning of those areas because GIS techniques are accurate and updated about the various patterns and socio-economic and environmental problems of these islands, beneficial for getting information. Such studies can inform and facilitate sustainable regional and local land use planning. Three periods, i.e.,1988, 2006, and 2024, were chosen for this study. Forest Cover Depletion or Deforestation of Mangroves, Agriculture Expansion, Settlement Growth, Coastal Erosion, and Wetland Changes are some of the most common reasons for LULC changes. These LULC changes are attributed to Population Pressure, Natural Disasters and Climate Change, economic activities, and Lack of Regulation. The main objectives of this study are to estimate the land loss and land cover changes from 1988 to 2024 and to investigate past and present scenarios of four islands based on LULC data.

2 Methodology

2.1 Study Area

Kutubdia Island. It is located at 21°49' N latitude and 91°51.5' E longitude in Cox's Bazar district and is an upazila in southeastern Bangladesh with an area of 215.79 km^2. It is characterized by a tropical climate, with an average temperature of 26 °C and monthly extremes ranging from 15 °C to 32 °C. The island receives considerable rainfall, with an annual average of 2824 mm, with July being the wettest month (768 mm) and January the driest (0.27 mm). The height of this island varies from 0 to 7.6 meters above sea level. Administratively, Kutubdia is divided into six unions, and according to the Bangladesh Population Census 2011, it had a population of 125,279.

Nijhum Island. It is the country's southernmost island, in Hatiya Upazila of Noakhali District, located at 22°5'35" N latitude and 91°00'13.7" E longitude. About 120 km south of Maijdee Bazar, the island is located at the confluence of the Meghna estuary and is part of the Noakhali Forest Division. Covering about 4565 hectares, 2023.428 hectares are designated as Nijhum Island Reserve Forest, managed by the Bangladesh Forest Department. The island began to emerge as a cluster of islands in the 1940s; in the 1960s, it was a small piece of sandy barren land, and in the 1970s, a devastating cyclone washed away almost all of it; later, it stabilized by 1972. The island is about 2.2 meters above sea level and has unstable mud flats due to estuarine activity. The island's population of 64,983 mainly consists of fishermen or farmers living in wooden or tin houses. Infrastructure is limited, with few paved roads, no land or air connectivity, and minimal healthcare and educational facilities.

Hatiya Island. Hatiya Island is in the southern part of Bangladesh within Hatiya Upazila of Noakhali District, at 22º39'59.99"N latitude and 91º12'E longitude. It is located at the northern mouth of the Bay of Bengal, where the Meghna River meets the sea. The island is bordered by the Meghna River and Noakhali to the north, the Bay of Bengal to the south, Manpura and Tajumuddin to the west, and Sawndip in Chittagong district to the east. The average length of an island in a north-south direction is about 48 km, and its width (east-west) is about 15 km on average. The total acreage of the island stands at 115,353 acres with an elevation estimated at 2.5 meters above mean sea level. The economy of Hatiya Island is mainly dependent on agriculture and fishing. The island experiences significant land use, land cover changes, and coastal changes due to human activities, coastal morphological processes, and tidal movements. The Intergovernmental Panel on Climate Change (IPCC) has identified Hatiya Island as a "major societal hotspot of coastal vulnerability", highlighting its environmental sensitivity and the need for targeted research.

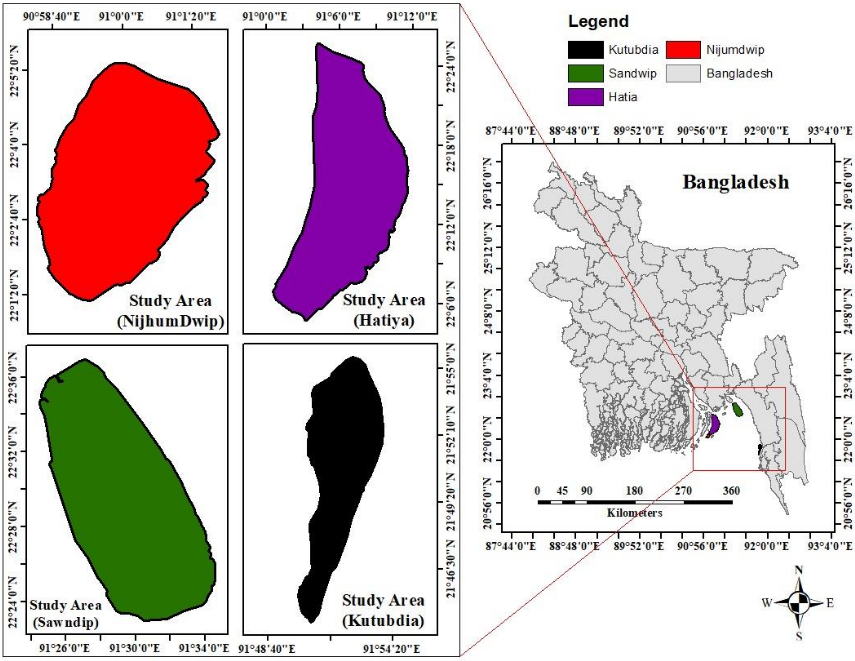

Fig. 1. Study area

Sawndip Island. It is a part of Sawndip Upazila in Chattogram District in southeastern Bangladesh, located at 22°29'N latitude and 91°29'E longitude. It is to the north by the Bamuni River, to the west by the Meghna River and Hatia Island, to the east by the Sawndip Channel and Sitakunda, and to the south by the Bay of Bengal [4]. This island is located on the floodplain of the young Meghna estuary and receives an average rainfall from 2000 to 3600 mm annually. Seasonal freshwater input of the Ganges-Brahmaputra Meghna River system greatly influences the water circulation and sediment distribution that favor land erosion. Along the estuary of the Meghna River, the island undergoes continuous geological change driven by the processes of erosion and accretion. Influenced by river sediments, wind, ocean currents, and tides of 4 to 6 m, the biggest part of the island was intertidal mudflats, which were submerged during high tide and emerged during low tide. Its coast has suffered great destruction because of coastal erosion, causing big environmental and socio-economic effects on this island. The island's shifting landscape, affected by erosion and accretion, is a significant area of concern in coastal management in Bangladesh. Additionally, population declines have been observed in erosion-prone areas of the island, particularly between 1981 and 2011. The four islands are assembled in Fig. 1.

2.2 Data Collection

The study uses multi-temporal Landsat satellite images and data to [5] analyse the spatial change (LULC) and temporal change (area change and bank side change) of Nijhum Dwip, Hatia, Kutubdia, and Sawndip from 1988 to 2024. Three different Landsat images are required for each island to compare the land use with spatial variation in these study areas for 1988,2006, 2024. For each island, three Landsat images were downloaded from The United States Geological Survey (USGS) site (https://earthexplorer.usgs.gov), shown in Table 1. The satellite images of Landsat 5 are a Thematic Mapper (TM) for 1988 and 2006, Landsat 8 Operation Al Land Imager (OLI), Landsat 9 Operation A1 Land Imager (OLI) and Thermal Infrared Sensor (TIRS) for 2024, respectively. These data were already georeferenced and orthorectified at the Universal Transverse Mercator (UTM) projection system (zone:46N, datum: WGS-84).

Table 1. Data collection information

Island	Sensor	Path/Row	Date of acquisition	Spatial resolution(m)	Cloud cover(%)
	Landsat 5 TM	136/45	10/11/1988	30	0
Nijhum	Landsat 5 TM	136/45	28/11/2006	30	0
	Landsat8OLI_TIRS	136/45	2/3/2024	30	0
	Landsat 5 TM	136/45	10/11/1988	30	0
Kutubdia	Landsat 5 TM	136/45	28/11/2006	30	0
	Lansat9OLI_TIRS	136/45	10/3/2024	30	0
	Landsat 5 TM	136/45	10/11/1988	30	0
Hatia	Landsat 5 TM	136/45	13/02/2006	30	0
	Landsat9OLI_TIRS	136/45	10/3/2024	30	0
	Landsat 5 TM	136/44	10/11/1988	30	0
Sawndip	Landsat 5 TM	136/44	28/11/2006	30	0
	Lansat9OLI_TIRS	136/44	10/3/2024	30	0

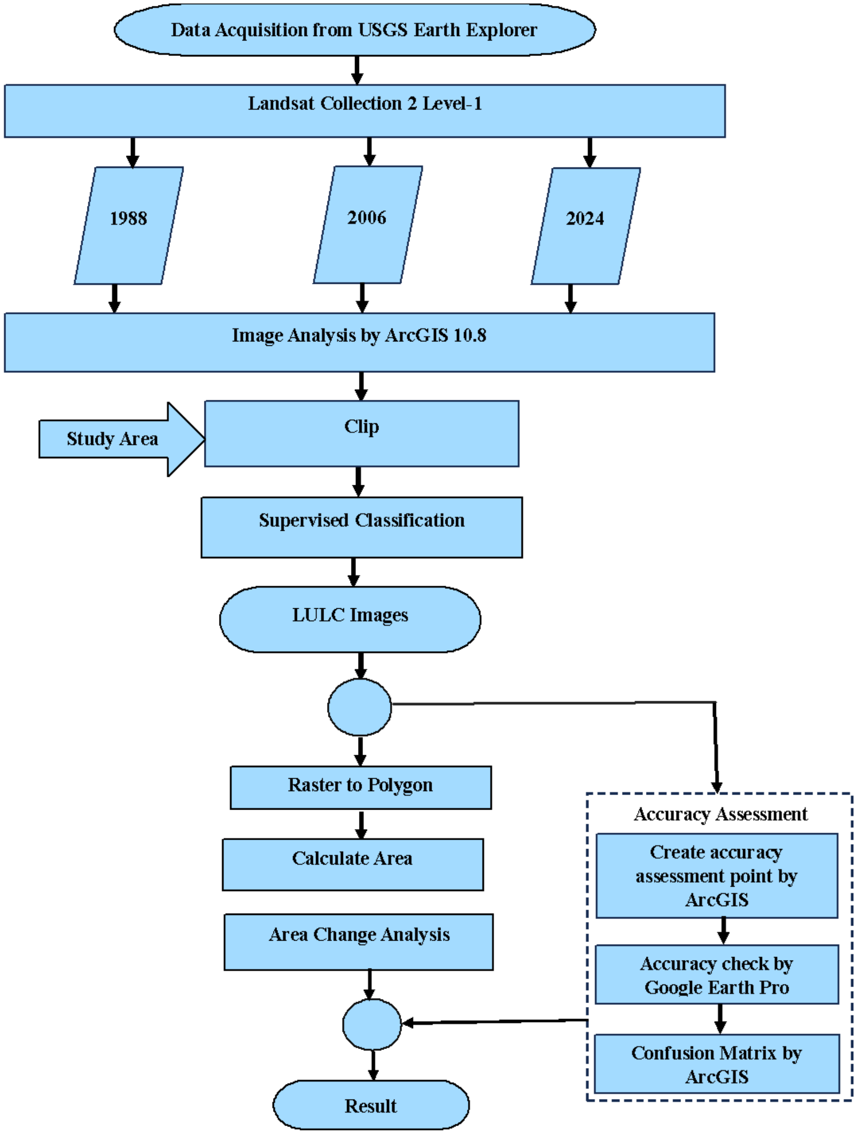

Fig. 2. Flow chart

2.3 Image Processing and LULC Detection

ArcGIS 10.8 version was used to process these LULC class detection processes, and Google Earth Pro was used for accuracy assessment processes. The supervised classification technique was used to classify the images. The supervised classification method is preferred to achieve high accuracy, interpretability, and consistency in the classification result compared to the unsupervised classification system. First, the study area has been selected and clipped from the composited band images. Using the classification toolbar, the islands are divided into different categories; among them, Kutubdia was divided into five categories: water body, salt pan, bare land, plantation, and mangrove forest; Sawndip was also divided into five categories: agriculture, bare land, water body, vegetation, and mangrove forest; and Hatia and Nijhum divided into four categories, bare land, water body, agriculture, and vegetation. Finally, they were classified using interactive supervised classification. The raster file was converted to polygons to calculate the area. Details of the procedure are shown in the flow chart in Fig. 2. Assessment points were created to increase the accuracy of the land cover mapping, and ground truth data was collected using Google Earth Pro. Finally, the accuracy percentage using the confusion matrix in ArcGIS has been calculated.

3 Result

3.1 Kutubdia Island

To analyse and measure Kutubdia Island's LULC, it was divided into five categories: salt pan, water body, bare land, plantation, and mangrove forests, as shown in Fig. 3. From 1988 to 2024, the total area of Kutubdia Island decreased by 13%. From 1988 to 2006, the total area decreased by 4%, and from 2006 to 2024, it increased by 10%. Despite this declining area, the salt pan area has increased continuously. 1988, it was 9.31 km^2, 15% of the total area. However, in 2006 and 2024, it increased to 24.63 km^2 (35%) and 25.80 km^2 (41%). On the other hand, the opposite scenario has been seen in the case of water bodies. In 1988, 2006 and 2024, the amount of water bodies was 10.69 km^2 (15%), 10.60 km^2 (15%) and 7.88 km^2 (12%), respectively. The bare land decreased significantly because new land was not added as a salt pan. Bare land in 1988 was 45.51 km^2, which is 62% of the total area; it decreased to 25.99 km^2 (37%) in 2006 and further reduced to only 16.52 km^2 (26%) in 2024. The amount of plantation in 1988, 2006 and 2024 was 5.29 km^2 (7%), 7.84 km^2 (11%), and 10.75 km^2 (17%) respectively. The amount of mangrove forest decreased by about 55% between 1988 and 2006, from 2.45 km^2 to 1.11 km^2. However, between 2006 and 2024, mangrove forests increased by about 158%. The results indicate overall accuracies of 87%, 79%, 81%, and the kappa index of 0.79, 0.69 and 0.72 for 1988, 2006 and 2024 respectively

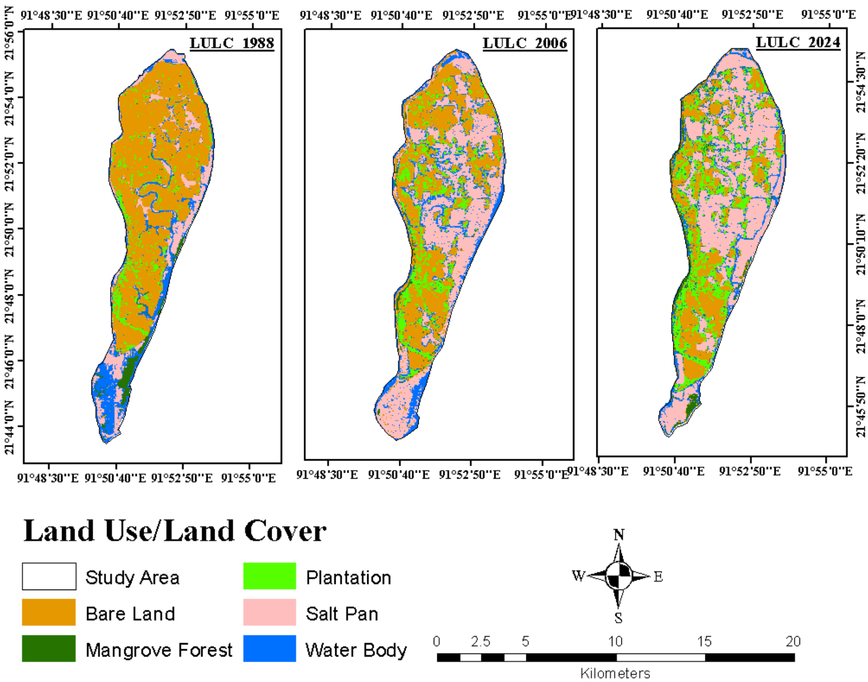

Fig. 3. Land use and land cover, Kutubdia Island

3.2 Nijhum Island

The Land Use Land Cover (LULC) study of Nijhum Island from 1988 to 2024 reveals significant changes driven by population growth and land use practices, as shown in Fig. 4. The island's agricultural land increased dramatically from 3.94 km² (10.66%) in 1988 to 11.27 km² (a 4% increase from 2006) due to the growing population converting forests into farmland. In contrast, vegetation decreased from 23.41 km² in 1988 to 17.94 km² in 2024, a 20% reduction over time. Water bodies showed irregular changes, shrinking by 41% between 1988 and 2006 but increasing again to 8.86 km² by 2024 due to riverine erosion and deposition. Bare land also fluctuated, expanding significantly in 2006 but later being repurposed for agriculture and housing. The island area increased by 31% in 2006 due to newly deposited soil but shrank by 3% in 2024. The overall accuracy of land classification for 1988, 2006, and 2024 was 95%, 86%, and 80%, respectively, with kappa indexes of 0.91, 0.83, and 0.72. People from nearby areas are settling on the island due to displacement from natural disasters, attracted by fertile land and fishing opportunities.

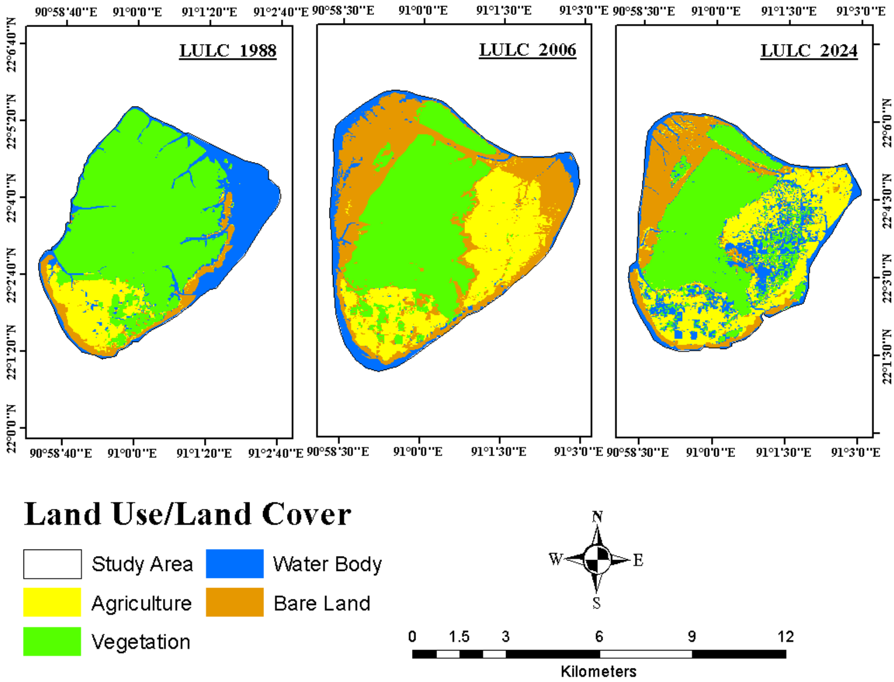

Fig. 4. Land use and land cover, Nijhum Island

3.3 Hatiya Island

The Land Use Land Cover (LULC) study of Hatia Island from 1988 to 2024 identified four main land categories: agriculture, water bodies, bare land, and vegetation, as shown in Fig. 5. Agricultural land dominated, covering 190.75 km² (45%) in 1988, peaking at 247.35 km² (68%) in 2006, but then decreasing to 169.74 km² (44%) by 2024. Conversely, vegetation steadily increased from 48.87 km² (11%) in 1988 to 130.72 km² (34%) by 2024, including natural forests and planted trees. Bare land fluctuated, starting at 77.75 km² (18%) in 1988, dropping significantly to 9.67 km² (3%) in 2006, but rising again to 77.80 km² (20%) by 2024. Water bodies decreased continuously, from 107.87 km² (25%) in 1988 to just 7.46 km² (2%) in 2024. The island's total area experienced fluctuations due to erosion and accretion at the Meghna River estuary, decreasing by 15% between 1988 and 2006 but recovering slightly by 2024. Land classification accuracy was 77% in 1988, 88% in 2006, and 83% in 2024, with kappa indexes of 0.64, 0.62, and 0.81, respectively.

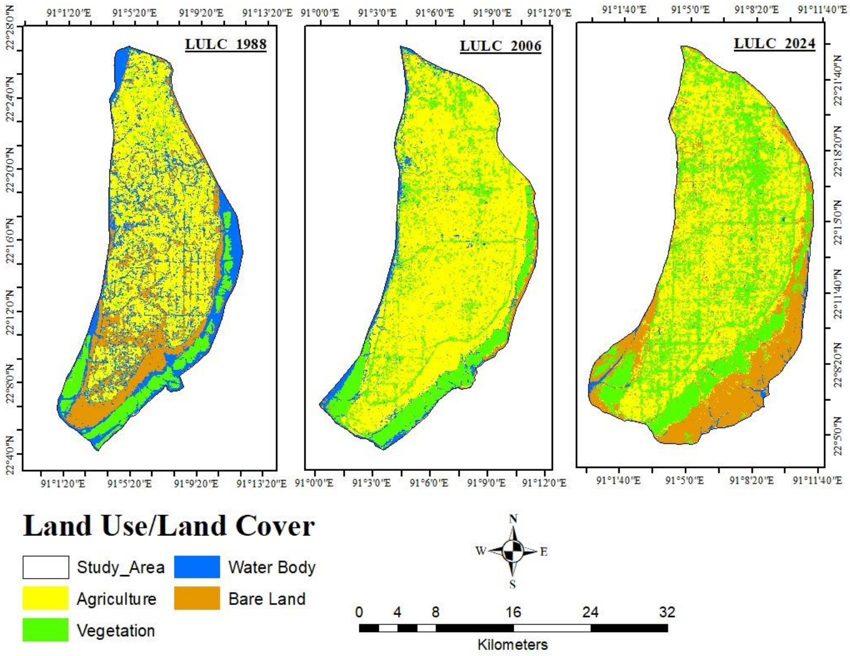

Fig. 5. Land use land cover, Hatia Island

3.4 Sawndip Island

The Land Use Land Cover (LULC) study of Sawndip Island from 1988 to 2024 categorized the land into agriculture, vegetation, water bodies, bare land, and mangrove forests, as shown in Fig. 6. Agriculture, a vital part of the island's economy, increased steadily from 66.48 km² (29%) in 1988 to 77.36 km² (32%) by 2024. Vegetation declined 14% between 1988 and 2006 but rebounded 36% by 2024, reaching 79.14 km² (28%). Water bodies consistently grew from 40.96 km² (18%) in 1988 to 68.04 km² (28%) in 2024. Bare land decreased by 33% between 1988 and 2006 but rose by 20% by 2024, reaching 42.87 km². Mangrove forests showed significant growth, from 2.61 km² (1%) in 1988 to 19.04 km² (7%) by 2024. The total island area increased by 22% from 2006 to 2024. Classification accuracy for land cover was 84% in 1988 and 2006 and 74% in 2024, with kappa indexes of 0.78, 0.79, and 0.66, respectively.

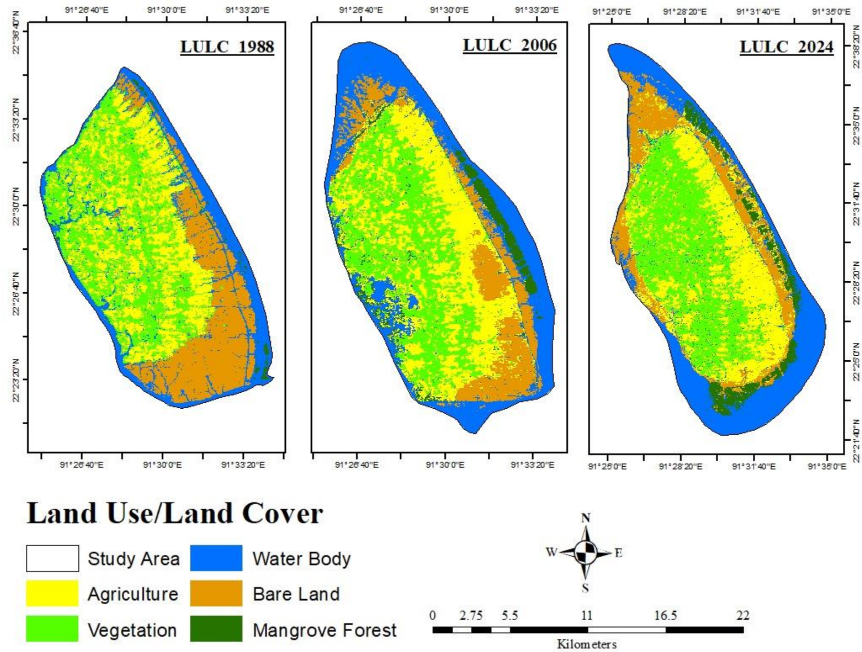

Fig. 6. Land use land cover, Sawndip Island

The study revealed that the land on the mentioned islands fluctuates and is influenced by erosion, sedimentation, and human activities. Nijhum Island gained 11.46 km² of land between 1988 and 2006 but lost 1.3 km² by 2024, a fluctuation primarily attributed to fluvial processes (erosion and degradation) and increasing population converting forests to farmland. In contrast, Kutubdia has continuously lost land, i.e., approximately 3.07 km^2 from 1988 to 2006 and 6.81 km^2 from 2006 to 2024. Despite this degraded area, the salt pan area has continued to increase, although salt pan expansion has compensated for some land. Another possible reason is that there was no addition of new land, and vacant land was used as salt pans. Hatia Island has seen significant erosion from 1988 to 2006, losing 63.7 km², then gaining 24.22 km² by 2024; the island's total area fluctuates due to erosion and accretion in the Meghna River estuary. On the other hand, in Sawndip, from 1988 to 2006, the land increased by about 3.33 km^2, then steadily gained land, increasing significantly by 51.88 km² from 2006 to 2024. The dynamics of the Meghna River estuary have played a significant role in the land change of all the islands except Kutubdia, where coastal erosion continues.

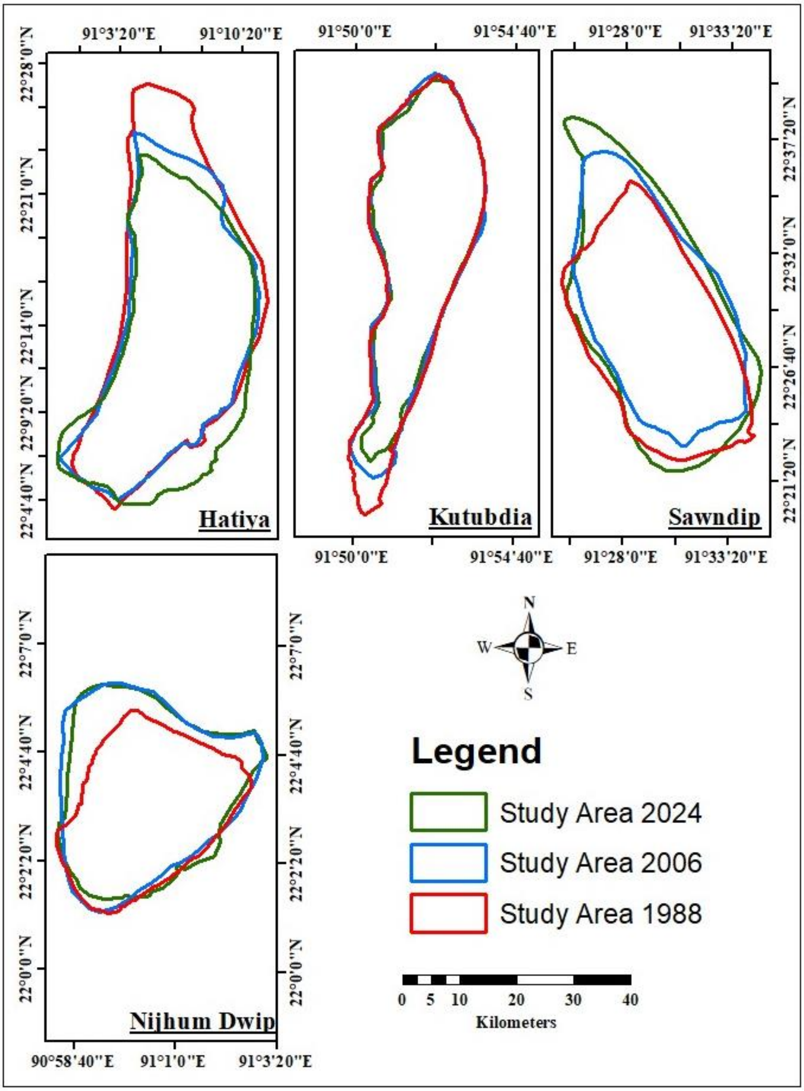

Fig. 7. Coastal line changes in four islands

The LULC analysis shows significant changes, with agricultural land increasing in the remaining islands except Kutubdia, where salt pans have expanded. After the initial decline, vegetation and mangrove forests show different trends with growth in Sawndip and recovery in Kutubdia. The research underscores the complex interplay between natural and human-induced factors affecting island morphology, providing insights into land management and coastal resilience strategies. Table 2 presents the land use and land cover data for four islands in the Chattogram coastal belt. Over the past 36 years, significant changes have occurred along the islands' shorelines. The coasts of the four islands in this case change temporally through natural processes that include erosion, sedimentation, sea level rise, storms, land reclamation, and construction. The land erodes or accumulates, changing the coastline's size and shape. The change in coastal line for islands is shown in Fig. 7.

Table 2. LULC change of four islands

Is-land	Class_Name	Area_km^2			Area change		
		1988	2006	2024	1988-2006	2006-2024	1998-2024
Nijhum	Agriculture	3.94	10.84	11.27	6.9	0.43	186%
	Vegetation	23.41	18.83	17.94	-4.58	-0.83	-23%
	Water Body	7.3	4.28	8.86	-3.02	4.58	21%
	Bare Land	2.28	14.43	9.03	12.15	-5.4	296%
	Total Area	36.93	48.39	47.09	11.46	-1.3	28%
Kutubdia	Bare Land	45.51	25.99	16.52	-19.52	-9.48	-64%
	Mangrove Forest	2.45	1.11	2.85	-1.34	1.75	16%
	Plantation	5.29	7.84	10.75	2.55	2.91	103%
	salt Pan	9.31	24.63	25.8	15.33	1.17	177%
	Water Body	10.69	10.6	7.44	-0.09	-3.15	-30%
	Total Area	73.24	70.18	63.37	-3.07	-6.81	-13%
Hatia	Agriculture	190.75	247.35	169.78	56.59	-77.56	-11%
	Vegetation	48.87	84.53	130.72	35.66	46.19	167%
	Water Body	107.86	19.98	7.46	-87.88	-12.53	-93%
	Bare Land	77.74	9.67	77.8	-68.07	68.12	0%
	Total Area	425.23	361.54	385.75	-63.7	24.22	-9%
Sawndip	Agriculture	66.48	71.03	77.36	4.54	6.33	16%
	Vegetation	68.11	58.4	79.14	-9.72	20.74	16%
	Water Body	40.96	58.21	68.04	17.24	9.84	66%
	Bare Land	53.06	35.7	42.87	-17.36	7.17	-19%
	Mangrove Forest	2.61	11.23	19.04	8.62	7.8	630%
	Total Area	231.24	234.57	286.45	3.33	51.88	24%

4 Conclusion

This research aimed to identify the changes in land use and land cover in Hatia, Kutubdia, Nijhum Dwip, and Sawndip. For this identification, remote sensing data and ArcGIS modeling demonstrated the changes in spatial and temporal land cover over thirty-six years. These land cover changes on those islands are significant. Three of these four islands, except Kutubdia, are located in the Meghna River estuary, which has seen continuous changes in these islands due to constant erosion and accretion. Between Nijhum Dwip and Hatia, the total land area is changing (decreasing and increasing). The long-term effects shown in Hatia, such as erosion, have been noticed in the northern and western zones. However, the Sawndip island is increasing in the area. In contrast, Kutubdia is facing dramatic shrinking. All factors include rising sea levels, tropical cyclones, warmer sea temperatures, and the melting of the Himalayas glaciers increasing flood and coastal erosion vulnerability. Moreover, the side of rising salt pans simultaneously decreases the amount of agricultural land, which puts further pressure on the food security for the growing population and hurts the ecological system of the island. The vegetation (forests) on Nijhum Dwip is decreasing quickly. With the increase in settlement, the forest land is being cleared and converted into agricultural land, which is a result of the ecological system of the island having a harmful impact. The government should adopt new land-use policies to deal with climate change's effects, protect agricultural lands from salinisation by building dams, and create new afforestation to reduce the impact of cyclones. Future studies of this type would have improved if high-resolution data (images) could be used, as well as field surveys and numerical modeling, which would help to know more accurately and in detail. This study has pointed out that the land use of those islands is constantly changing, which allows the policymakers to see the land pattern of these islands.

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