

DOI: <https://doi.org/10.3329/jnujles.v10i2.85259>**Research Article****ASSESSING SEVERITY OF ECOLOGICAL INTEGRITY DEPLETION USING SATELLITE IMAGERY: THE CASE OF CENTRAL COAST OF BANGLADESH****Md Fuad Hassan, Nawshin Tabassum, Tazrian Rahman Noirit, Nusrat Kona, and Riffat Mahmood****Department of Geography and Environment, Jagannath University, Dhaka-1100, Bangladesh**Received: 13 February 2025,**Accepted: 08 May 2025***ABSTRACT**

Climate change and anthropogenic activities has altered the land along the central coast of Bangladesh. It is already documented that this region faced different climate induced hazards and disasters due to lack of natural protections such as mangroves. Besides soil erosions are prominent in this region causes loss of ecosystem capacity to provide service. This study aims to assess the ecosystem integrity depletion and the impact severity of changing land in the ecological context over two decades (2000-2024). Using the Landsat imagery in Google Earth Engine (GEE) platform this study assessed the Land Use and Land Cover (LULC) for the year 2000 and 2024 and calculated the changes of land categories. Spatial severity of impact (SSI) is calculated from these changing land categories and the ecosystem integrity (EI) is also calculated for two years to assess the depletion of ecosystem from the base year 2000. The study found that the highest reduction has been observed in crop land, accounting for 69.4% to 52.5% of total area. The increasing number of homestead vegetation with rural settlement from 964.1 to 1602.9 sq.km reflects the increasing anthropogenic stress of the study area while waterbodies has been almost doubled from 2000 to 2024 indicating intensified erosion. Furthermore, the highest 58.5% of total areas facing moderate level of severity impact due to the negative alterations of land while eight unions across three districts had most of the areas (over 70%) facing very high impact of negative land alterations and most of these regions are on the edge of the Meghna estuary. On the other hand, the assessment of ecosystem integrity has shown that it reduced from 30963.6 to 29990.5 sq.km reflection of lowering ability of the land is mainly due to the degradation of land. The study also identified that almost 47.3% of total land is facing high depletion of ecosystem where 24.3% of total land have experienced very high degradation from the base year along the Meghna River estuary and the north eastern part of the study area. The improvement of the ecosystem also

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seen in most of the islands and in the central part of the study area. Among all other unions Hajipur union's 98.57% of total areas experienced higher degradation. The Kala para upazila have highest six number of unions have more than 70% areas high ecological degradation. The results of this research are pertinent in explaining the spatial configuration of ecological vulnerability in the extremely dynamic coastal setting will help policymakers and environmental managers to implement sustainable coastal land-use strategies, mitigating adverse ecological impacts and promoting resilience.

Keywords: *Bangladesh, coast, GIS, RS, ecosystem integrity, spatial severity of impact*

Introduction

The term "integrity" was first used in the context of ecology in 1949 by renowned environmentalist Aldo Leopold (González, 2023). Karr and coworkers later defined it as "the ability to support and sustain a balanced, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats within a region." (Karr, 1981; Karr and Dudley, 1981). But these ability of an ecology are being depleted due to the alterations of land for anthropogenic causes (Jiayu *et al.*, 2024) and as well as for the natural impact like climate change (Leal Filho *et al.*, 2021). Growing human-induced pressures and climate-related hazards are leading many ecosystems to lose their ability to maintain ecological balance and services (Wolff *et al.*, 2017). Additionally, sea-level rise (SLR) and global warming will have detrimental long-term effects particularly on coastal ecosystems (Klema, 2011) further intensifying ecosystem's vulnerability. Land use change, sedimentation, soil erosion, water pollution, and overfishing are some of the non-climatic stressors that affect coastal ecosystems (Saroar *et al.*, 2015). Approximately 1.5 million hectares of land have been salinized and their habitat destroyed over the past three decades due to the uncontrolled growth of saltwater shrimp farming, which is frequently accomplished by destroying rice fields, marshes, and mangroves (Paul and Vogl, 2011). Particularly when it comes to biodiversity, the effects of various climatic and non-climatic stressors are intricate and frequently site-specific (Dickinson *et al.*, 2015). Therefore, the most vulnerable and exploited natural systems in the world are coastal ecosystems (Halpern *et al.*, 2008) and Bangladesh's coast is one of the areas most exposed to the effects of climate change due to its distinct physiography (Hossain *et al.*, 2017). Every year different types of natural calamities such as, floods, cyclones, tidal surges, and salinity intrusions are among the many hydro-meteorological disasters that affect Bangladesh's whole coastal region (Saroar *et al.*, 2019). Among the other coasts the central coast of Bangladesh facing higher erosional and accretional activity due to the Meghna River. Because of the Meghna Estuary's delicate low-lying physiographic state, significant seasonality in weather, and freshwater flow, it is susceptible to natural disasters and hazards such coastline erosion, saline intrusion, tropical storms and their associated storm surges, etc (Mahmood *et al.*, 2020). Besides the region has experienced severe land-use changes, soil erosion, and loss of natural habitats due to urban expansion, agricultural intensification, and rising sea levels (Mahmood *et al.*, 2023). These

changes threaten the ecological balance, necessitating an assessment of the severity of ecological integrity depletion and land degradation using satellite-based Earth observation techniques.

Worldwide different study have conducted about ecosystem integrity (Caniani *et al.*, 2016; Nasr and Orwin, 2024; Reza and Abdullah, 2011; Selsamet *et al.*, 2024; Verweij *et al.*, 2014) and land degradation (Abdel, 2023; Gashaw *et al.*, 2014; Pásztor, 2021; Szabó *et al.*, 1998) separately using satellite-based Earth observation techniques. All of these studies individually find out the spatial pattern and quantification different scenario of ecosystem integrity and degradation pattern. Some studies have conducted to find out the land use change impact on a particular ecosystem (Canianiet *et al.*, 2016; Tejaswi, 2007) where a study of Hagenlocher (2012) assessed ecosystem degradation around displaced settlements, highlighting the relevance of such methods for monitoring ecological integrity loss using remote sensing techniques focusing on anthropogenic pressure. Although, there aren't many analytical studies and tools that offer readily scalable data that measure variations in environmental pressures caused by various demands, such management, planning, and monitoring tasks (Riato *et al.*, 2023; Zhao and Huang, 2022).

There are many study for coastal areas of Bangladesh focusing on the land use and land cover change (Islam *et al.*, 2016; Islam and Zannat, 2023; Nath *et al.*, 2023) while some other studies assessed the future land use change by incorporating different parameters (Islam *et al.*, 2020; Islam *et al.*, 2023). Previous literatures identified that the coastal areas are facing severe negative land alterations (Hoque *et al.*, 2022) which may causes lowering the ecosystem ability. Different studies have conducted about the ecological province identification and ecosystem threats (Zaman *et al.*, 2021) and vulnerability of environmental degradation (Hassan *et al.*, 2015). Different land use driven factors and the impact of land use on several environmental parameters related studies identified the rapid anthropogenic pressure on this region (Adnan *et al.*, 2020; Ara *et al.*, 2021; Xu *et al.*, 2020).

In context of ecosystem of the coastal area of Bangladesh several researchers focused on several aspects of ecosystem. According to several studies, there is strong evidence that the coastal social-ecological system of Bangladesh is changing more quickly than it has in the past due to a variety of interrelated factors, such as increased storminess, sea level rise, new land uses, altered river flows, population growth, internal migration, urbanization, and more robust conservation measures (ADB, 2005; Hossain *et al.*, 2016; Miah *et al.*, 2023). Despite having a highly functional and physically diversified ecology, Bangladesh's coastal ecosystem is progressively deteriorating. As a result, many members of the coastal community are seeing a deterioration in their standard of living (Iftekhar, 2006). However, the Meghna River estuary has been crucial to the coastal community's livelihood for decades, yet it is under significant strain from anthropogenic forces. A study of Miah *et al.* (2021) identified numerous risks and stressors, both natural and man-made, have been found to be responsible for changes in ecosystem services in the central coast of Bangladesh. These include overexploitation, illegal and destructive fishing,

siltation of the riverbed, and natural hazards such floods, intense cyclonic storms, and sea level rise. There are several scattered research that focus on various biological elements of the coastal estuary system in Bangladesh (Hossain *et al.*, 2007) but the ability of the estuarine ecology in Bangladesh has not yet been thoroughly examined (Miah *et al.*, 2021) particularly the Meghna river estuary's severity of ecological depletion is still unseen. Therefore, this study will attempt to fill these knowledge gap.

The main aim of this study is to identify the spatial severity and pattern of ecosystem depletion as well as quantifying the depleted area over two decades by incorporating the land alterations through GIS and remote sensing techniques. The methodology applies the spatial severity index and ecological integrity index to detect and map areas that have undergone significant ecological transformation. This spatially explicit analysis highlights some of the sensitive areas that require conservation and provides insight into how degraded the ecosystem can be. The findings are intended to support evidence-based coastal management, enhance ecological resilience, and contribute to sustainable development planning in vulnerable coastal areas.

Materials and Method

Study Area

The central coast of Bangladesh is a region of significant ecological importance, characterized by its diverse ecosystems and rich biodiversity. Administratively the central coast of Bangladesh makeup with 18 upazilas under six districts consists 35.04% of total population (BBS,2011). A fluvio-marine floodplain created by the deposition of sediments from the Brahmaputra-Ganges-Meghna Rivers and its distributaries (Sarwar, 2013), the central coast of Bangladesh, also known as the Meghna Estuary (Mahmood *et al.*, 2020), is situated between 21°48' ~ 22°52' north and 90°12' ~ 91°40' east. As a result, it is characterized by a number of offshore islands (Roy and Mahmood, 2016). Micro to meso-tidal coastal ecosystems predominate in this flat relief area (Mahmood *et al.*, 2020). Mostly silty, stratified, and slightly calcareous in nature, the topography is primarily smooth of this region (Coleman, 1969). With a tropical monsoon climate, the Meghna Estuary's mean daily temperature fluctuates from roughly 18°C during the dry season to 30°C before the monsoon arrives, when there is typically between 2000 and 3600 mm of rainfall annually (Brammer, 2014; Mahmood *et al.*, 2020).

Bangladesh's coastal region contains a variety of ecosystem types that are susceptible to both climatic and non-climatic stresses, such as mangroves, marshes, natural canals, and floodplains (Nandy *et al.*, 2013). Due to the low-lying funnel shaped physiographic conditions of the central coast of Bangladesh is more vulnerable to climate change than other coasts and facing different level of hazards and disasters every year (Brammer, 2012; Mahmood *et al.*, 2020; Mahmood and Mahbub, 2018). Besides due to the river activities this region is more prone to soil erosion makes the regions ecosystem more vulnerable. The central coast is therefore selected as an area for study due to its ecological fragility, high human density, and urgent need for risk-informed planning and conservation, as well as its representative sensitivity to climate change (Figure-1).

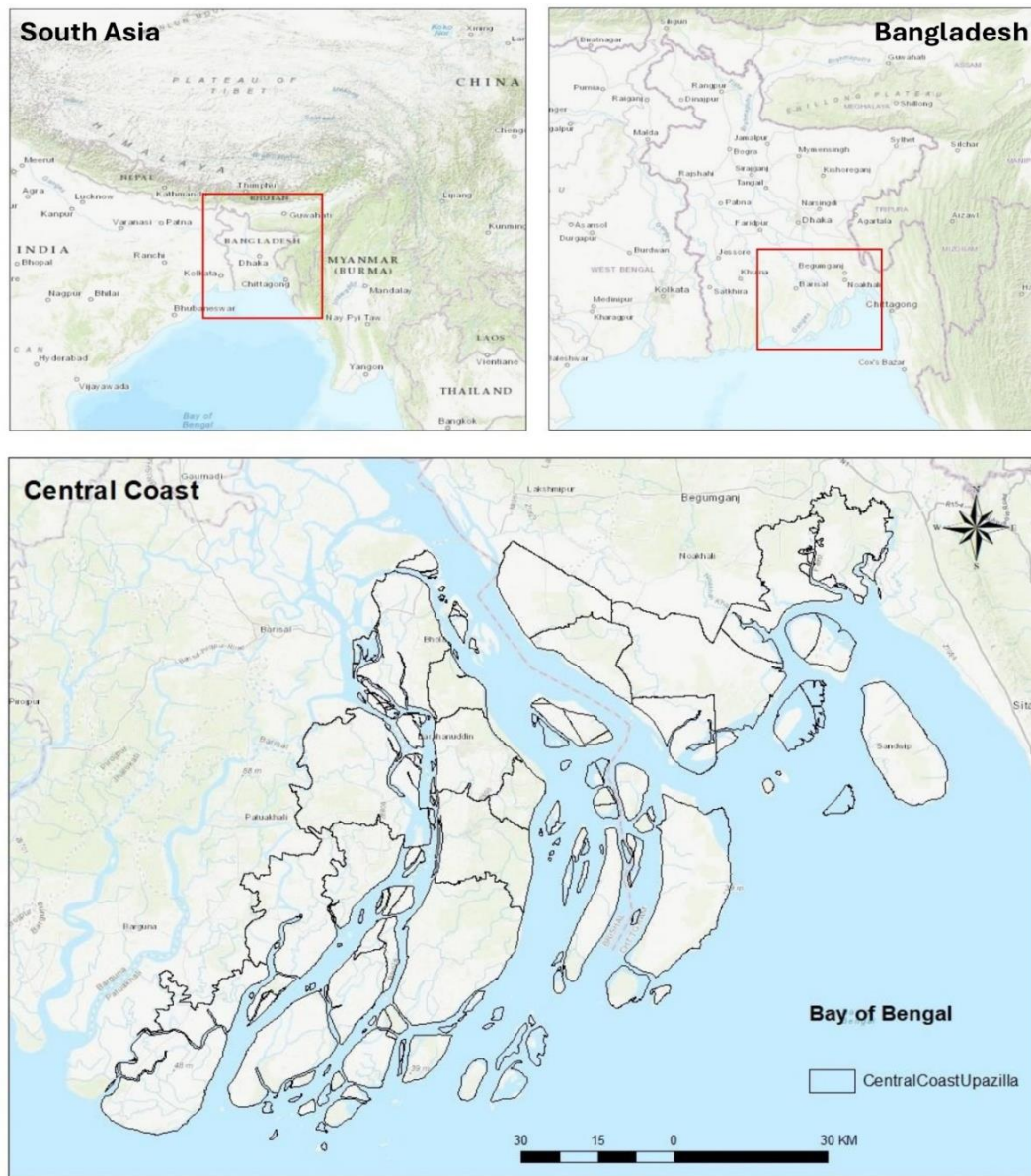


Figure 1: Study Area

Dataset

This study used two types of Landsat images for two-time frame (Table-1) collected from the U.S. Geological Survey (USGS) through google earth engine (GEE) javascript API. The year 2000 is considered as a base year in this study.

Table 1: Data source

Criteria	Timeframe	Data Source	Resolution	Type	Type/Product
LULC	01/01 /2000 – 01/10/2000	Landsat-5 image courtesy of the U.S. Geological Survey	30m × 30m	Yearly Median	Level 2, Collection -2, Tier-1
	01/01 /2024 – 01/12/2024	Landsat-9 image courtesy of the U.S. Geological Survey	30m × 30m	Yearly Median	Level-2, Collection-2, Tier-1
SSI	Calculated from LULC		30m × 30m	Pixel Wise	
EID					

Assessment of Land Use and Land Cover (LULC)

Google earth engine (GEE) javascript platform is used to conduct the LULC of the year 2000 and 2024. It is an open source cloud based computing application which provides a large scale processing and storage capacity (Tesfaye *et al.*, 2024). GEE provides preprocessed datasets and enables all processes to be completed with a single script, which makes it advantageous to use (Mahmood *et al.*, 2023). Cloud masking, image filtration, geometric, radiometric and atmospheric correction are made for each year Landsat images. This study used two different scripts to classify the image for two different years. The whole study area is identified into eight classes namely, Crop Land, Homestead Vegetation, Dense vegetation, Barren land, Mudflat, Aquaculture, Water-bodies and Built-up Area (Table-2). Prior knowledge about the subject area and the literature evaluation are used to determine the classification category (Abdullah *et al.*, 2019; Akber *et al.*, 2018; Mahmood *et al.*, 2023; Hoque *et al.*, 2022).

Landsat 5 Thematic Mapper sensors level 2, collection 2, tier 1 satellite imagery and Landsat 9 operational land imager (OLI) sensors level 2, collection 2, tier-1 satellite imagery are used to assess the land use land cover map for the year 2000 and 2024 respectively. To obtain the less cloud contaminated images this study selected those images that have less than 10% cloud contamination. The median images from 1st January to 31th Decembers are composited to utilize for both years. Prior research has demonstrated that the median composition techniques produced more precise findings (Phan *et al.*, 2020).

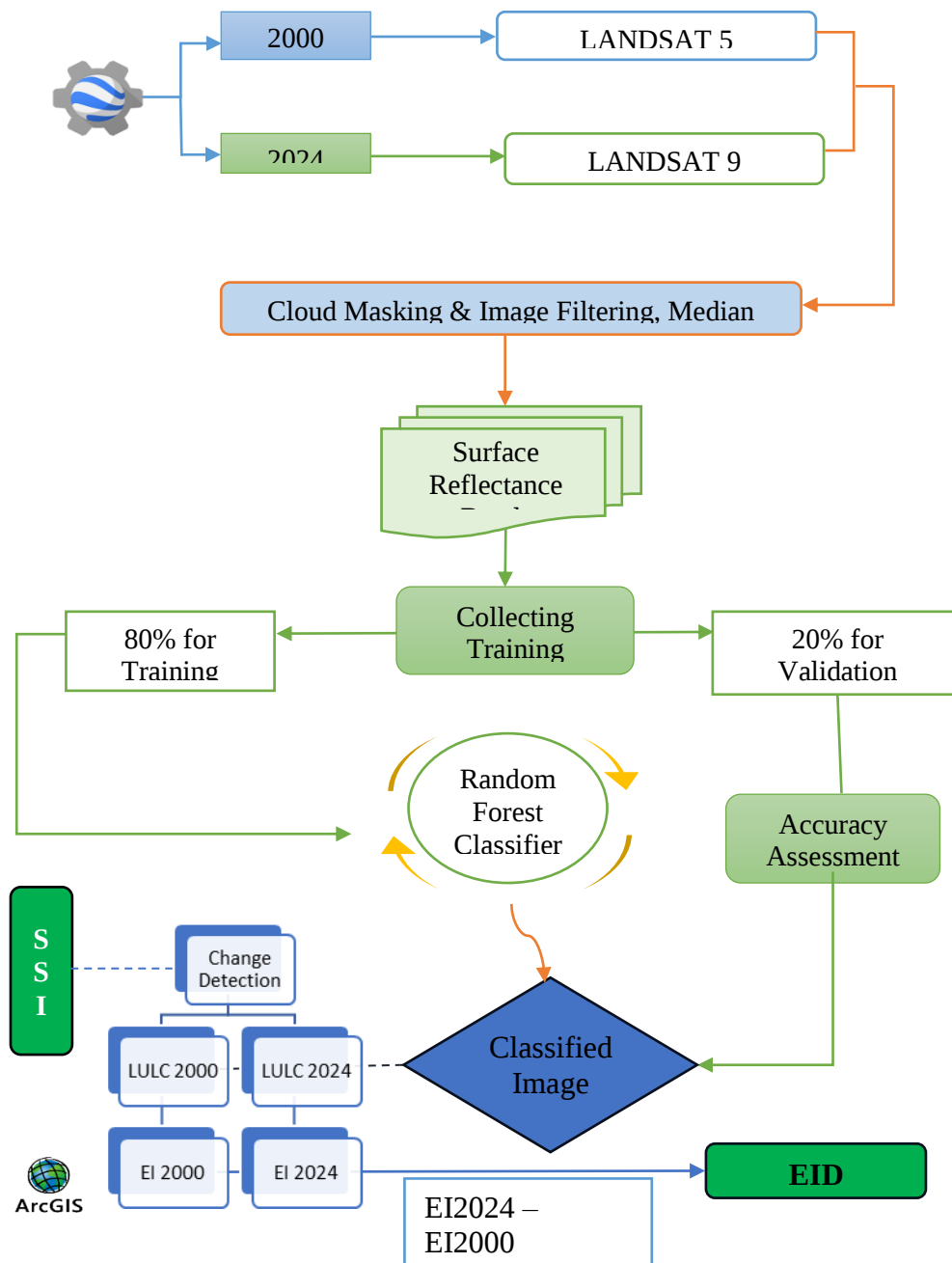


Figure 2: LULC Methodological Flowchart

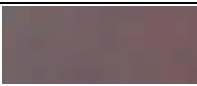
Table 2: LULC Class Description

Class	Description
Crop Land	Agricultural land, Grass Land
Homestead Vegetation	Homestead Vegetation, Sparse vegetation
Dense vegetation	Mangrove Forest
Barren land	Barren land, Agricultural Fellow
Mudflat	mud
Aquaculture	Shrimp Farming, Salt pan, Wetland
Waterbodies	River, Inland water
Built-up Area	Settlement, Household

To represent each class properly the training samples were taken in the forms of polygons and point features by identifying their unique spectral signatures (Table-3). In order to ensure accurate classification, a total of 2,500 samples were collected for the year 2000, while 2,000 samples were taken for the year 2024. Training samples are combined into a single dataset and split into training and testing categories. Among the total samples 80% of them used to train the model and rest of 20% were used for the validation for both years. Numerous classification algorithms are available for LULC mapping, including fuzzy classification (FC) (Badhe and Chang, 2016), random forest (RF) (Khelifi and Mignotte, 2020; Koschke *et al.*, 2012), artificial neural network (ANN) (Thanh Noi and Kappas, 2017), maximum likelihood (ML) (Otukey and Blaschke, 2010) etc. Due to the popularities and provides higher accuracy and efficiency, low computational cost this study used the RF method to classify the images. Seven reflectance bands for Landsat-9 namely, SR_B1, SR_B2, SR_B3, SR_B4, SR_B5, SR_B6 and SR_B7 are composited while six reflectance band namely SR_B1, SR_B2, SR_B3, SR_B4, SR_B5 and SR_B7 composited for the year 2000.

Table 3: Spectral Signatures of LULC Classes

LULC Class	Landsat-5 False Color Composite	Landsat-9 False Color Composite
Crop Land		
Homestead Vegetation		
Dense vegetation		
Barren land		

Mudflat		
Aquaculture		
Waterbodies		
Built-up Area		

To evaluate the reliability of the classified LULC map, an accuracy assessment was performed within the Google Earth Engine (GEE) platform. The validation of the classification was done with reference data through stratified random sample. Reference samples were derived from high-resolution satellite imagery available in GEE. Since evaluating accuracy is an essential part of the classification process, a confusion matrix was created in order to compute common accuracy metrics, such as overall accuracy and the Kappa coefficient, which are used to analyze the LULC's performance. Overall accuracy provides a basic measure of accurately identified occurrences, while the Kappa coefficient accounts for agreement arising by probability (Khan *et al.*, 2024). These metrics are widely recognized in remote sensing literature for their complementary strengths in classification validation. This study remained reasonable accuracy with a total classification accuracy of 95.12% in 2000 and 83.72% in 2024. The corresponding kappa coefficient values were 0.94 and 0.82, respectively. In order to further evaluate the ecological parameters, these categorized images were exported into ArcGIS version 10.8 while maintaining the appropriate precision.

Assessment of Spatial Severity of Impact (SSI)

Spatial Severity of Impact (SSI) is the method which measures the extent and intensity of the effects or the degree of impact for a particular event into an area. This study used SSI as an ecological parameter to evaluate the severity of impact across different areas, as ecological and environmental effects can vary from place to place for the same event. Depending on changes in land cover and land usage, any landscape experiences both positive and negative changes over time (Mahmood *et al.*, 2023).

Considering these changes for ecosystem, each class of the classified image assigned a score ranging from 0-7 (Table-4) based on previous literature review and expert opinion. In this study Dense Vegetation has been assigned highest score 7 as the increase of dense vegetation over time will reflect the positive changes in the ecosystem such as higher carbon sequestration, land stabilization, biodiversity etc., where water bodies have been assigned lowest score due to the higher erosion and salt water intrusion in the study area. After assigning the score following the table for each year, change analysis is performed into the ENVI 5.6 and later it exported into the ArcGIS 10.8. Following the table-4 SSI value is calculated based on the equation-1 from the change analysis (Fig-3).

$$SSI = (TC - BC) \quad (1)$$

Here, TC is the score of the transformed class in change analysis (in this study year 2024)

BC is the score of the Base class in change analysis (in this study the year 2000)

Table 4: Score based on contribution in Ecosystem

LULC class	LULC Score based on impact	References
Crop land	5	Moderate impact due to soil degradation and agricultural runoff (Foley <i>et al.</i> , 2005)
Homestead Vegetation	6	Transitional zone providing semi-natural habitats but altering natural landscapes (Giri <i>et al.</i> , 2013).
Dense vegetation	7	High ecological value; loss severely affects biodiversity and ecosystem services (Hansen <i>et al.</i> , 2013).
Barren land	2	Low productivity and ecological value but minimal ongoing anthropogenic impact (Liu <i>et al.</i> , 2024).
Mudflat	3	Critical for nutrient cycling and biodiversity, vulnerable to conversion and degradation (Murray <i>et al.</i> , 2014).
Aquaculture	4	Causes habitat loss, water pollution, and wetland degradation (Naylor <i>et al.</i> , 2000).
Waterbodies	0	Essential ecosystems with minimal degradation impact (Lehner <i>et al.</i> , 2006)
Built-up	1	High degradation impact due to urbanization and habitat destruction (Seto <i>et al.</i> , 2012)

[Source: Author,2024]

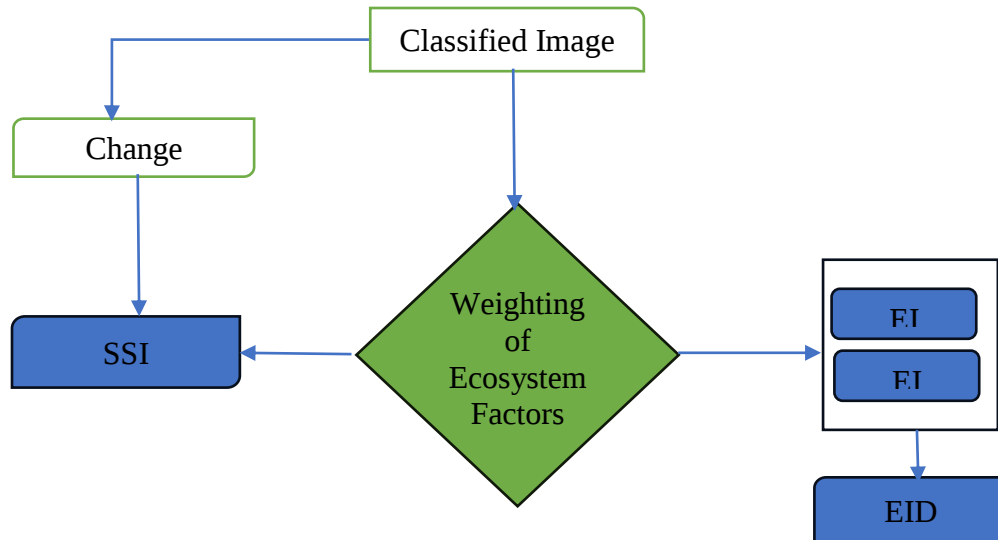


Figure 3: SSI and EID Methodology

Assessing Ecological Integrity Depletion (EID)

To calculate the Ecological Integrity (EI) for the year 2000 and 2024, area of each classified images was calculated in Sq.km in ArcGIS 10.8. Based on the assigning score from table- 3, Equation -2 (Hasan *et al.*, 2021; Mahmood *et al.*, 2023) is followed and calculated the ecological integrity value for each year (Fig-3).

$$EI = \sum_{i=0}^n = A_i * C_i \quad (2)$$

Here EI = Ecosystem integrity value

i-n = LULC classes

A_i = Area of each LULC class

C_i = LULC class score

After calculating the EI for 2000 and 2024, equation-3 (Hasan *et al.*, 2021) is followed to calculate the Ecological Integrity Depletion (EID) of that area.

$$EID = EIL - EIB \quad (3)$$

Here,

EID = Ecological Integrity Depletion

EIL = Ecological Integrity of Later year (EI~2024)

EIB = Ecological Integrity of Base year (EI~2000)

Results and Discussion

Land use Land cover dynamics (2000-2024)

The study identified that the central coast of Bangladesh has been faced huge alterations of land from 2000 to 2024. The crop land has reduced from 69.4% to 52.5% indicating that crop land has been altered in different land categories with its total area reduction from 4392.7 sq.km in 2000 to 3320.6 sq.km in 2024. Homestead vegetation increased from 15.2% to 25.3% shows the anthropogenic stress in this region. Homestead vegetation is mainly increased due to the increasing number of rural settlements in this area. The increasing number of rural settlements with homestead vegetation has a combined impacts on the environment.

Table 5: LULC Pattern (2000- 2024)

Class	2000		2024	
	Area (Sq.Km)	%	Area (Sq.km)	%
Crop Land	4392.7	69.4	3320.6	52.5
Homestead Vegetation	964.1	15.2	1602.9	25.3
Dense Vegetation	362.0	5.7	374.8	5.9
Barren Land	78.6	1.2	68.5	1.1
Mudflat	60.7	1.0	108.6	1.7
Aquaculture	100.1	1.6	172.0	2.7
Waterbodies	358.8	5.7	647.9	10.2
Built-up Area	10.6	0.2	32.3	0.5

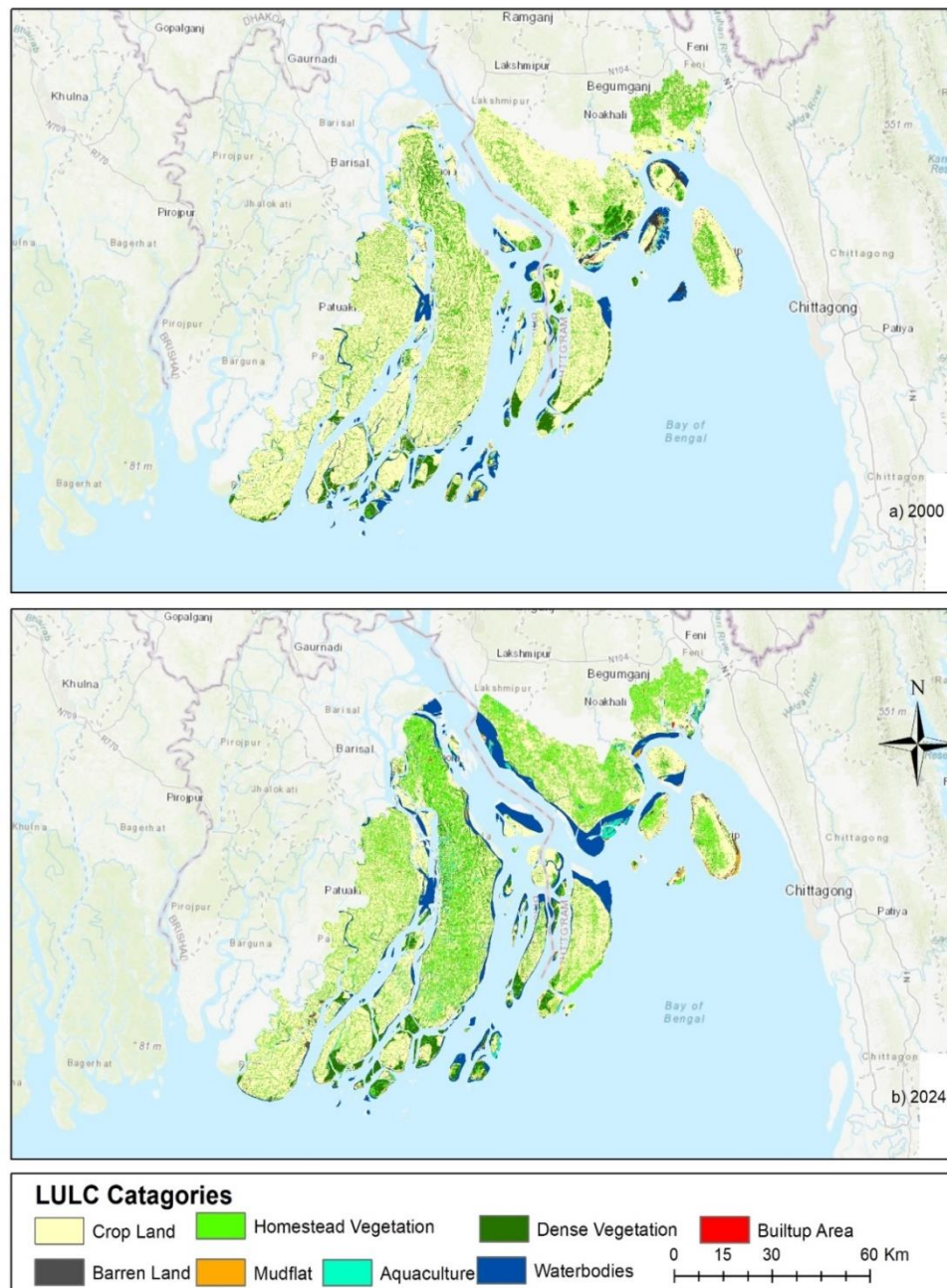


Figure 4: LULC Map a) 2000 b) 2024

A positive change can be noticed for the ecosystem from 2000 to 2024 that dense vegetation increased from 362 sq.km to 374.8 sq.km due to the natural increase of mangrove and other dense vegetation. Barren land has almost same percentage from 2000 to 2024 which is 1.2% to 1.1% of

total land. Mudflat increased from 1% to 1.7% of total area due to the deposition of sediments in these areas. Aquaculture increased from 100.1 sq.km to 172 sq.km is mainly reflecting the anthropogenic stress over this area. Waterbodies are being doubled almost in this time period from 358.8 sq.km to 647.9 sq.km. is mainly due to erosion of land specially in the edge of Meghna estuary (Fig-4). Built-up areas are increased which is 10.6 sq.km to 32.3 sq.km. The increasing number of built-up areas reflecting the anthropogenic stresses are in increasing trend from 2000 to 2024 may lead to the ecosystem degradation (Table-5).

Spatial Severity of Impact (SSI)

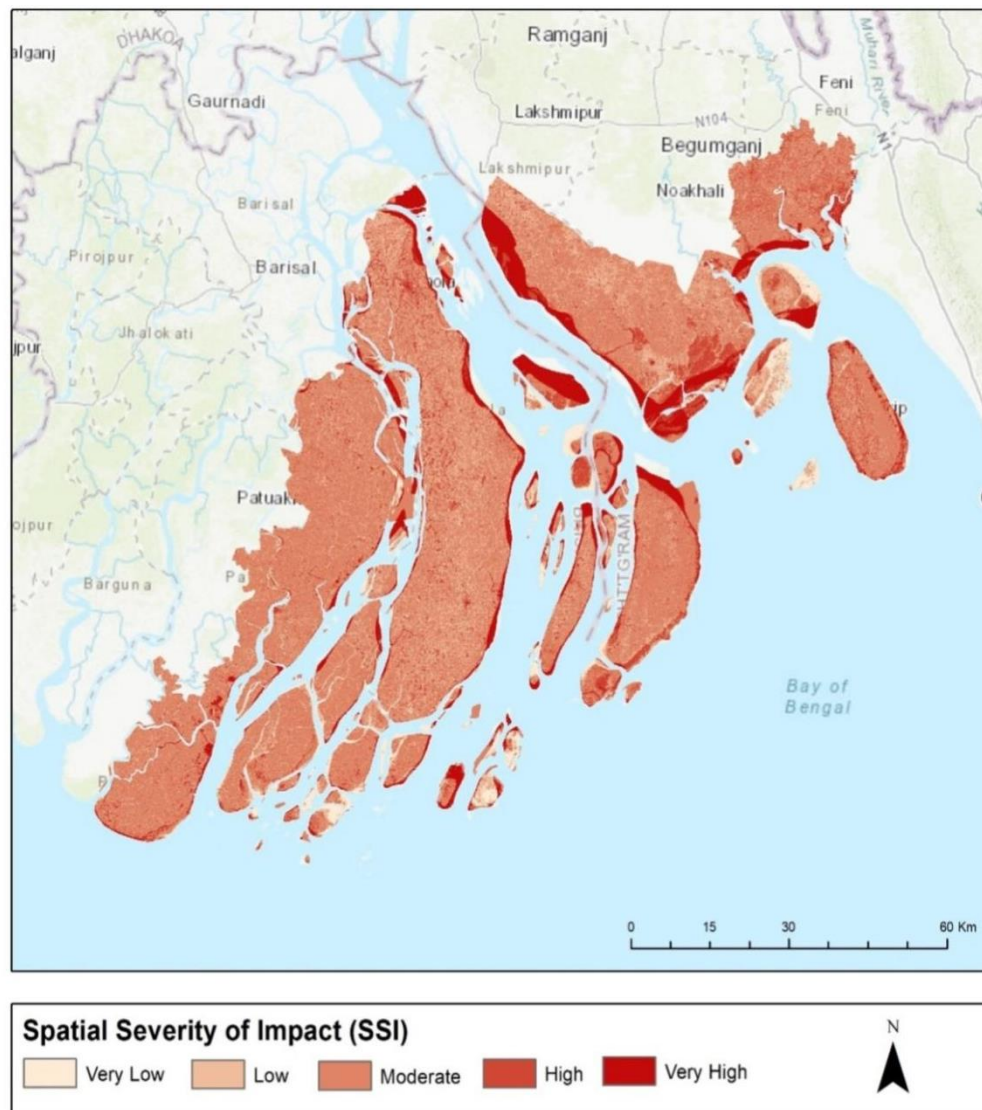


Figure 5: Map of Spatial severity of Impact (SSI)

The SSI shows the severity of impact due to land alterations on a particular ecosystem. Severity mainly depends on the alterations of land. The study found very low severity level is 2-7 consists 285.5 sq.km which is 4.5% of total land mainly shows the positive changes on land likely increasing on dense vegetation or mangrove or other vegetations. Almost 17.9% of total land has been faced low severity (0-2) from the base year 2000 to the recent year 2024 which reflects the positive change on land categories and it's created positive impact on ecosystem (Table-6). These positive SSI has a positive impact on ecosystem combinedly covers almost 1418.1 sq.km area.

Table 6: SSI level analysis

Severity level	SSI Score	Area (Sq.Km)	%
Very Low	2-7	285.5	4.5
Low	0-2	1132.6	17.9
Moderate	-1 -0	3702.8	58.5
High	-3 - -1	617.9	9.8
Very High	-7 - -3	590.1	9.3

The area with -1-0 SSI value represents the moderate severity level accounting for 58.5% of total area. This study identified most of the areas are facing moderate level of severity due to the alterations of land combined with anthropogenic and natural causes. There are in total 19.1% of total land are facing high to very high level of severity due to severe negative alterations of land. These areas SSI values ranging from -3 to -7 mainly in the edge of the Meghna estuary and most of the islands of central coast Bangladesh (Fig-5).

Table 7: Area with over 70% of area under High to Very High Severity

Division	Districts	Upazila	Union	Total Union Area (Sq.km)	High to Very High area of SSI (Sq.Km)	%	Severity Level
Barishal	Bhola	Daulat khan	Hajipur Union	2.2	2.1	97.0	Very High
			Bhabanipur Union	1.4	1.0	71.6	Very High
		Hatiya	Nalchira Union	10.2	8.4	81.9	Very High
Chattogram	Lakshmipur	Kamalnagar	Char Kalkini Union	15.5	15.2	97.6	Very High
			Char Falcon Union	11.3	10.2	89.8	Very High
			Saheberhat Union	19.8	14.1	71.1	Very High
		Ramgati	Char Abdullah Union	28.1	24.2	86.2	Very High
	Noakhali	Tazumuddin	Bara Malancha Union	15.7	12.9	82.3	Very High

There are eight union under 5 upazila's over 70% of land facing very high severity due to negative alterations of land (Table-7). Among these unions Char Kalkini union under Kamalnagar upazila, Lakshmipur districts have highest percentage of land under very high severity accounting for 97.6% of total land. In terms of upazila level severity Kamalnagar have highest number of unions with 70% more areas of total area under very high impact of land alterations. Under the Bhola district there are two upazila with three unions falls under this category. The result shows that the portions of Chittagang division's ecosystem have facing more severe impact than other areas (Fig-6).

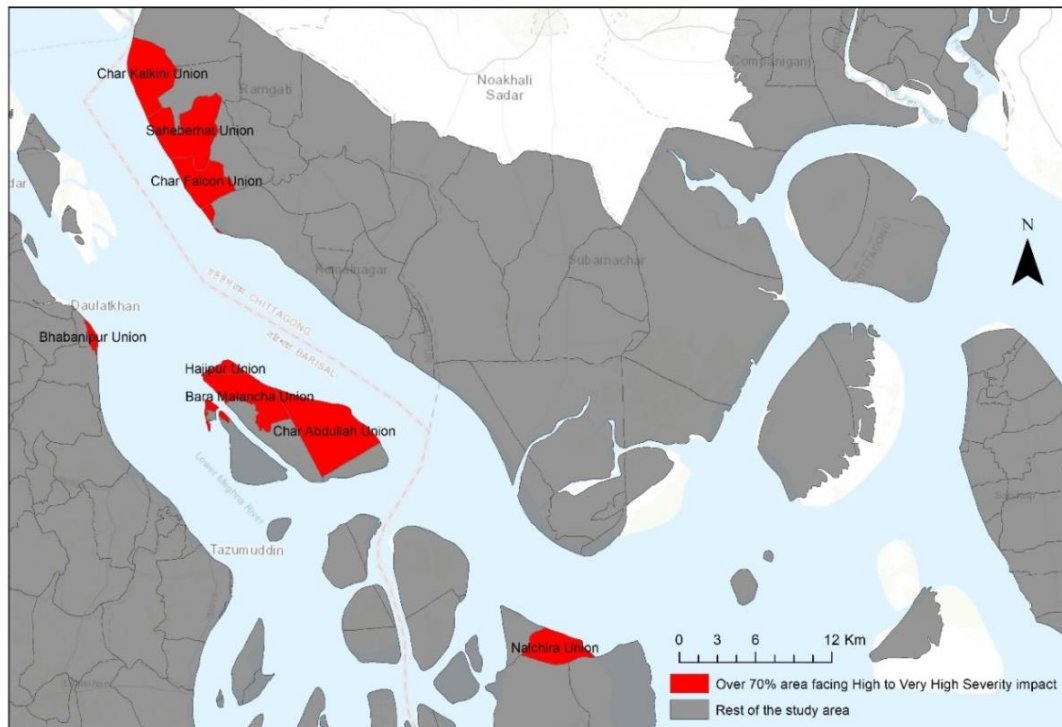


Figure 6: Unions with high to very high severity impact over 70%

Ecosystem Integrity Depletion

Ecosystem integrity is an important indicator that reflects the capacity of ecosystems to maintain structure, function, and resilience in response to natural and anthropogenic changes. The highest declined is observed in the cropland from 2000 to 2024 accounting 42559.6 to 33359.5 sq.km, showing the depletion in ecosystem capacity (Table-8). The homestead vegetation and dense vegetation's ecosystems capacity is increased from 2000 to 2024 accounting respectively 5784.7 to 9617.5 sq.km and 2533.7 sq.km to 2623.4 sq.km. All other land classes have also enjoyed positive change in ecosystem capacity thus the class-based ecosystem increased has been shown positive trend excluding the crop land (Table-8). In terms of total areas ecosystem in 2000 was 30963.6 which was later depleted into 2990.5 sq.km reflecting these areas are facing several negative alterations of land. This study assessed the ecosystem depletion scenario from 2000 to

2024 to assess the ecosystem health of an area over time (Fig-7). The EID value -21963.27-12345.72 represents the very high level of deterioration from 2000 to 2024 accounting for 24.3%

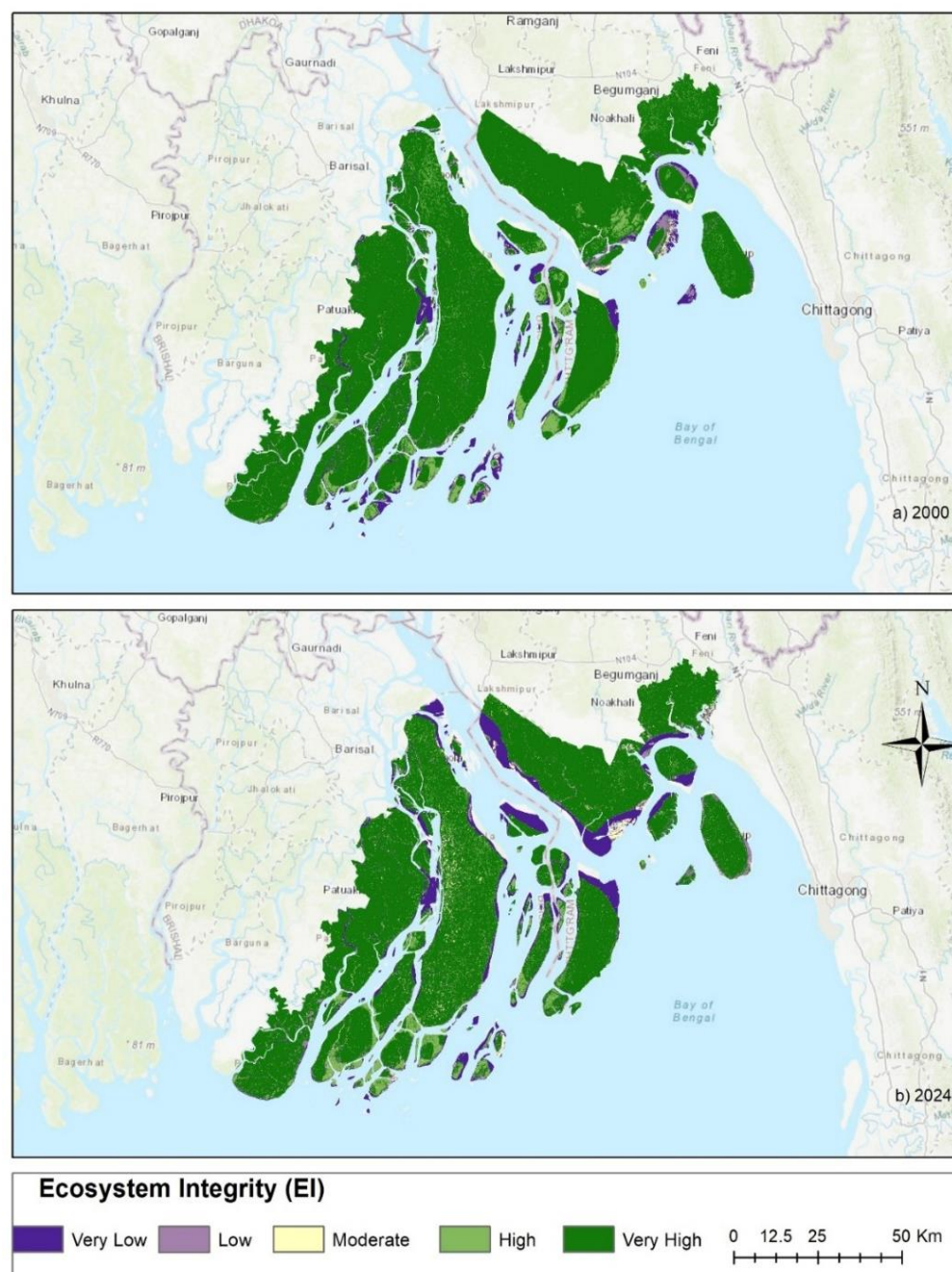


Figure 7: EI of 2000 and 2024

of total area (Table-9). These areas has experienced very high level depletion or negative alterations like urbanisation, rapid deforestation or soil loss due to the meghna river activity. Most of the very high depletion has been seen on the edge of the meghna estuary and along some island's edge of these area (Fig-8) The main cause of these areas are experienced soil loss and thus reduced the land ecosystem capacity. The deterioration value -12345.72 - -3161.31 represents the high deterioration in the largest portion of the study area accounting for 2991.5 sq.km area which is 47.3% of total land. These regions ecosystems are highly facing the depletion that reduced the ecosystem capacity. There are almost 7.9% of total land has moderate level of depletion which may lead to the further depletion but not in the severe case at present. The area with 687.90 – 7083.83 depletion score represents the lower depletion than the base year. These areas may enjoyed a positive changes on ecosystem. There are 8.2% of total land faced very low depletion is mainly reflects the positive alterations of land likely mangrove afforestation, increasing number of vegetation, improvement of vegetation health etc thus the capacity of an ecosystem enjoyed the improvement.

Name	EI 2000 (Sq.Km)	EI 2024 (Sq.Km)
Crop Land	21963.2	16603
Homestead Vegetation	5784.7	9617.5
Dense Vegetation	2533.7	2623.4
Barren Land	78.6	68.4
Mudflat	182	325.7
Aquaculture	400.2	687.9
Waterbodies	0	0
Buildup Area	21.2	64.6
EI (Sq.Km)	30963.6	29990.5

Table 8: Class-wise ecosystem integrity

Deterioration level	EID	Area (Sq.Km)	%
Very High	-21963.27--12345.72	1535	24.3
High	-12345.72--3161.31	2991.5	47.3
Moderate	-3161.31- 687.9	501.2	7.9
Low	687.90-7083.83	772.6	12.2
Very Low	7083.83-16603.01	518.9	8.2

Table 9: Deterioration Level

Most of the islands edges and some portions of north eastern part of the study areas are showing the improvement of ecosystem representing with green to dark green color on the map (Fig-8).

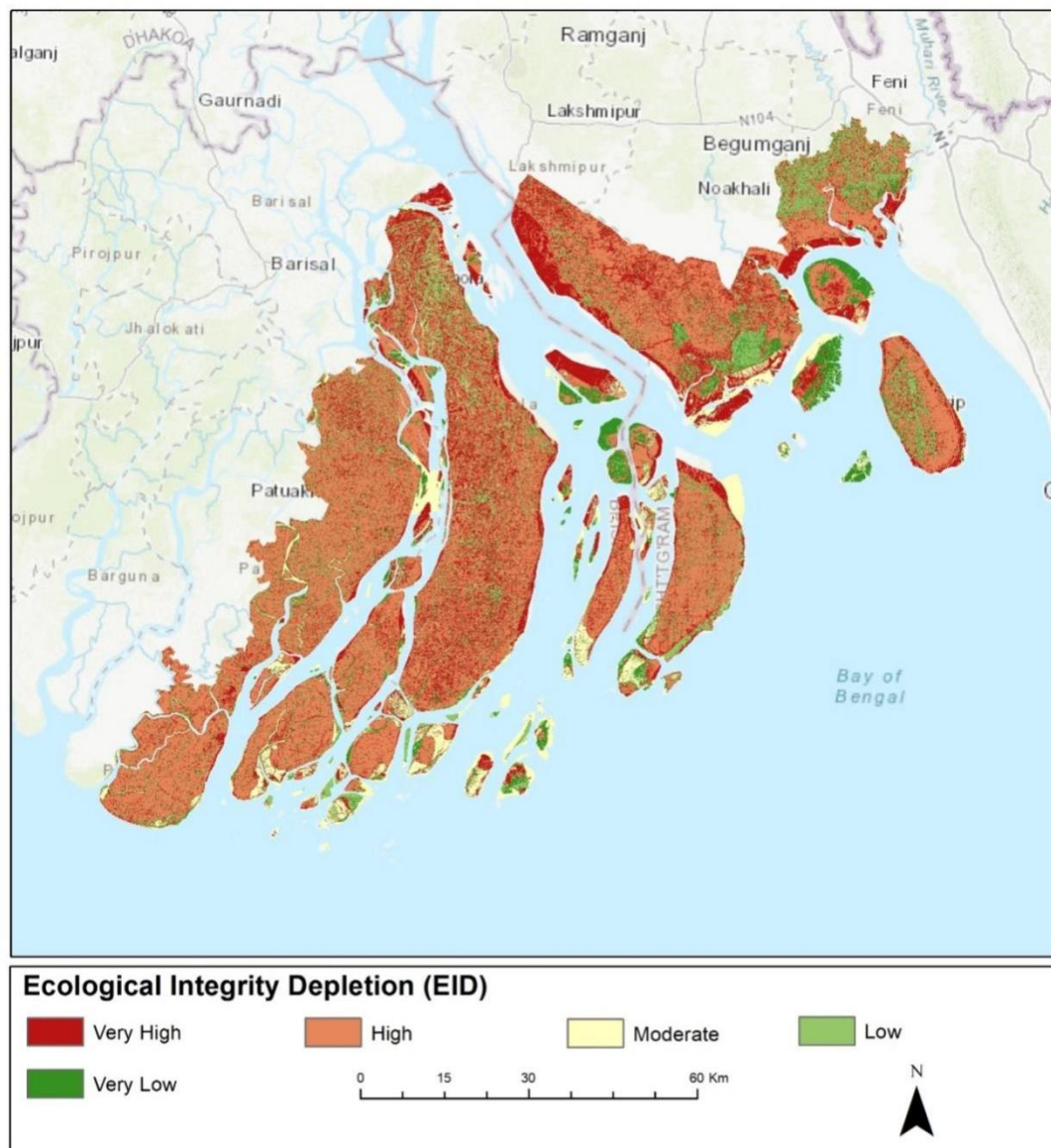


Figure 8: EID from 2000 - 2024

Table 10: Area with 70% more under high to very high depletion

Division	District	Upazilla	Union	Total area(Sq.Km)	High to Very High area of EID (Sq.Km)	Percent	EID Level
Barishal	Patuakhali	Galachipa	Amkhola Union	46.21	33.28	72.02	High
			Bakulbaria Union	23.78	17.47	73.48	High
		Kala para	Baliatali Union	41.62	32.38	77.80	High
			Chakamaiya Union	35.81	26.90	75.10	High
			Dalbuganj Union	24.75	18.50	74.74	High
			Lata Chapli Union	32.59	24.08	73.91	High
			Mithaganj Union	30.93	22.99	74.32	High
			Tiakhali Union	26.88	19.74	73.43	High
	Bhola	Daulat Khan	Hajipur Union	2.19	2.16	98.57	Very High
		Tazumuddin	Bara Malancha Union	15.67	12.62	80.52	Very High
Chattogram	Noakhali	Hatiya	Burir Char Union	74.22	54.30	73.16	High
			Sonadia Union	41.01	30.14	73.50	High
	Lakshmipur	Kamalnagar	Char Falcon Union	11.35	10.57	93.13	Very High
			Char Kalkini Union	15.54	13.39	86.17	Very High
			Saheberhat Union	19.79	14.20	71.74	Very High
	Chittagang	Sandwip	Digghapar Union	3.38	2.55	75.36	High
	Feni	Sonagazi	Char Chandia Union	11.25	8.24	73.24	High

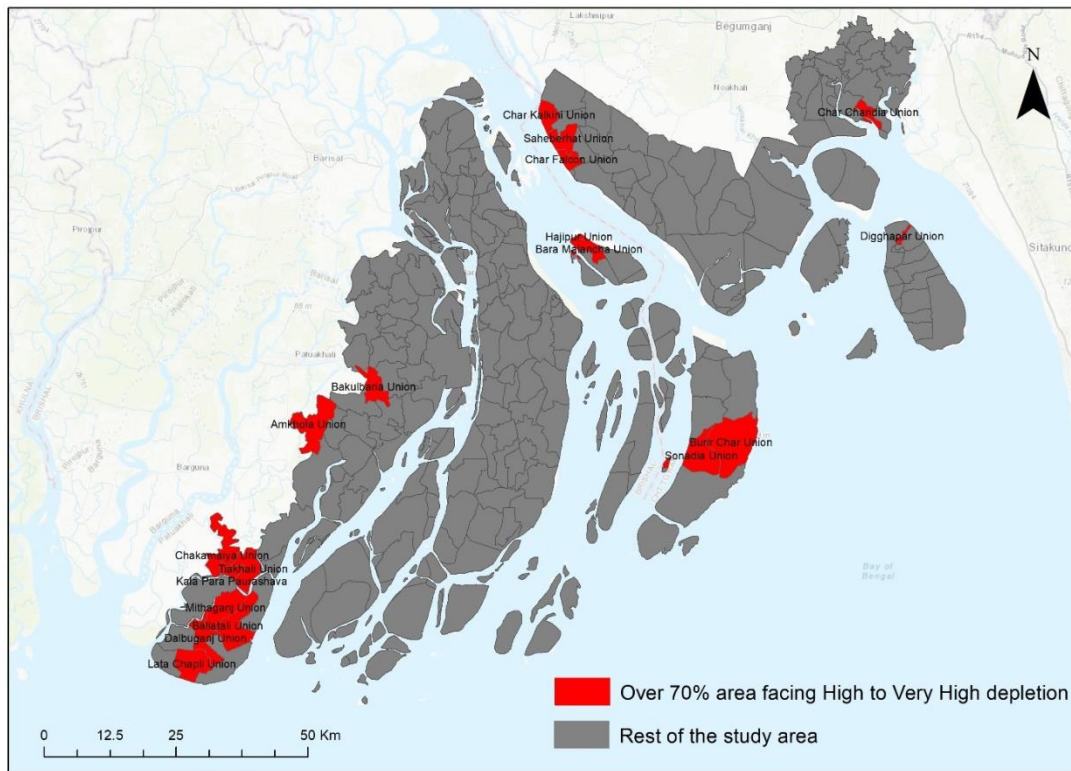


Figure 9: Unions over 70% area under high to very high depletion

This study identified there are 17 unions under 6 districts have over 70% of area consists with high to very high ecosystem integrity depletion (Table-10). Among the Barishal division there are two districts which have 10 unions under 4 upazilas are facing high to very high depletion. In Barishal division among all other upazillas Daulat khan and Tazumuddin upazila's have two union namely Hajipur union and Bara Malancha union's respectively 98.57% and 80.52% areas under very high depletion. These areas lands are facing severe negative alterations for ecosystem as there soil erosions are more prone. Among the Chittagang district, Char Falcon union, Char Kalkini and Saheberhat unions most of the areas faced severe deterioration. The Sandwip and Sonagazi upazila's most of the areas faced 1 upazila faced high deterioration (Fig-9).

The Meghna Estuary of Bangladesh is a unique place where a continuous process of land formation and erosion takes place due to a complex interaction between higher river discharge, massive sediment load, strong tidal forces, wind actions, waves, salinity and cyclonic storm surge, and estuarine circulation (Alam *et al.*, 2014). In coastal regions of Bangladesh, the most frequent LULC trajectory is from crop or cultivated land to rural settlement construction (Hoque *et al.*, 2022). This study found that crop land has been faced severe negative alterations which is reduced from 69.4% to 52.5%. Due to the growing anthropogenic pressure and conversion of crop land into the waterbody or mudflat as a depositional and accretional process, the crop land has

been reduced over time. The study also found that the home stead vegetation with rural settlement has been increased over time showing the similar pattern of increasing number of tresses outside the forest while dense vegetation remains almost in stable amount compared to previous. The growth in the waterbodies (almost twofold in last 20 years) is largely explained by the fact that the lower Meghna River was widened at a point close to the estuary where masses of rivers, Jamuna and Padma meet to pour tons of waters and sediments. Although a given amount of localized land accretion has been evidenced, there is such fluvial outburst at such littoral confluence combined with the recent height of sea level that the lower Meghna shoreline has become very vulnerable to erosion (Shahid *et al.*, 2024). This fact corresponds to similar conclusions drawn by Allison (1998), Brammer (2014), and Steckler *et al.*(2022), who pointed to the active process of changing sediment and hydrological interactions that constantly change the estuarine geometry. Therefore, one element contributing to the expansion of open water areas in the region has been the loss of land along riverbanks and coastal margins due to erosion.

Furthermore, this study identified the negative alterations of land that may degraded the ecosystem. The study found that most of the areas of central coast has been faced moderate level of negative changes in land use or land cover. About 19 percent of the entire area is affected by negative alterations that are high to extremely high in severity. Char Kalkini Union in Kamalnagar Upazila and Hajipur Union in Daulat Khan Upazila have the highest of these, with 97 percent of the former and 97.6 percent of the latter being negatively impacted by the extensive land change. Previous studies founds that these land has facing severe alteration due to the erosional activity and other natural hazards and disasters (Amin *et al.*, 2021; Aziz *et al.*, 2009; Siddiqui, 2014) which may reason for the higher severity and lowering in ecosystem integrity. Most of the land categories except cropland have high ecosystem integrity compared to the base year. The spatial pattern of ecosystem integrity depletion found in this study that more than 70% of total area fall into the high to very high category. This result reflects that these areas face severe ecosystem pressure and require urgent priority intervention (UPI) (Mahmood and Mahbub, 2018). In district level the Patuakhali district has more than 70% of total area under high ecosystem integrity loss. The Kala para upazila of Patuakhali district has the highest number of union (6 union) with high ecosystem integrity depletion. A study of Emran *et al.*, (2020) found that in order to preserve ecological balance, several regions needed to be improved and called for UPI.

Focusing on the ecosystem degradation using GIS and remote sensing technique used in this study is a new attempt which identified the spatial pattern of ecosystem integrity and severity as well as the most degraded unions over two decades. Also, this study illustrates the significance of earth observation tools in the fast-changing socio-ecological landscape. This study asserts that ecosystem-based adaptation, in addition to land use planning, afforestation, and erosion control strategies, is critically important for restoring and maintaining the ecological integrity of Bangladesh's coastal areas.

Conclusion

This study provides an in-depth understanding of land use and ecosystem changes along the central coast of Bangladesh from 2000 to 2024 using geospatial analysis. As Meghna estuary or the central coast has a dynamic physiography and facing high interaction of river discharge and

erosion continuously the authors thought the ecosystem of this changing environment should be examined. Therefore, this study founds a significant landscape transformation—particularly the cropland declined much more and increases in homestead vegetation, waterbodies, aquaculture, and built-up. The reason behind these changes is a combination of growing anthropogenic stress and dynamic natural processes like river erosion and sediment deposition near the Meghna Estuary. Furthermore, over 20% of the entire region is experiencing high to extremely high levels of impact, and several unions has facing severe ecological deterioration. The results also enlighten the existing trend of the change of land use and how it may affect the ecological balance and resilience of the coastal ecosystem. At policy level, the study gives critical evidence of incorporating ecosystem health and land change monitoring into the local and national planning systems. It can be used in formulation of strategies like climate-resilient land use zoning, afforestation in coastal regions, erosion control, and ecosystem-based adaptation. Special measures are especially needed in those unions that have been defined as hotspots of ecosystem integrity loss.

However, the study also has certain limitations. It relies primarily on satellite-based LULC classification and derived indices, which may not fully capture ground-level nuances or short-term seasonal changes. Additionally, the absence of high-resolution socio-economic or ecological field data may limit interpretation of underlying causes in some areas. So, the future research should focus on how to predict future hazards by including more field-based ecological assessment, socioeconomic factors of landscape change, and predictive modelling. Overall, it is evident that the proposed study demonstrates the value of spatial analysis and earth observation in tracking ecological changes over time and location. It offers a foundation for evidence-based planning and encourages multi-level stakeholders to concentrate more on ecological restoration and sustainable land management in Bangladesh's coastal regions that are at risk.

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