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Research Article

Changing Patterns of Vegetation and Its Impact on Carbon Sequestration in Saint Martin's Island from 1990 to 2020

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Abstract

Saint Martin's Island seems to float in the Bay of Bengal and it has importance in aspects of geographical condition, international policy, marine resources collection, and protection of the country. The unique biodiversity of Saint Martin's Island attracts numerous researchers and tourists alike, eager to explore its rich ecosystem. The present study was conducted for the determination of vegetation degradation and its impact on carbon storage of the unique Island in Bangladesh. Data were collected through the ArcGIS software, Land Use and Land Cover, Normalized Difference Vegetation Index, and InVEST model. The findings indicated that the built-up area, and cropland area increased 11.66% and 9.16% respectively from 1990 to 2020. The maximum built up area increased from 2010 to 2020. On the other hand, the aquatic land area, vegetation area, and barren land area decreased 0.032%, 13.57%, and 6.93% respectively from 1990 to 2020. The total carbon storage was 6.97×10^4, 6.05×10^4, 5.60×10^4, and 5.09×10^4 (Mg) in 1990, 2000, 2010, and 2020 respectively. The total carbon decreased 0.92×10^4, 0.45×10^4, and 0.51×10^4 (Mg) from 1990 to 2020, and the highest decreased between 1990 and 2000. The findings revealed that vegetation and carbon storage declined at a geometrical rate due to infrastructural development and over tourism activities, which lead to loss of biodiversity in Saint Martin's Island. The authority should promote ecotourism-based activities and ban all commercial tourisms. Conservation strategy, coastal zone management, and impact assessment monitoring will also be developed for the protection of the unique Island of Bangladesh.

Keywords

Biodiversity, Climate Change, Degradation, Endangered Species, Habitat

1. Introduction

Saint Martin's Island lies in the northeastern Bay of Bengal, at the southernmost part of Bangladesh. It is approximately 9 km south of the Teknaf Peninsula and about 8 km west of Myanmar's northwestern coast, near the mouth of the Naf River. The island covers roughly 8 km^2 and contains sandy shores, intertidal areas and rocky habitats [1, 2]. Although it is commonly called Bangladesh's "coral island," the island itself is sedimentary; coral communities occur on the surrounding rocky substrate [2]. Fishing, tourism, agriculture and related work contribute to local livelihoods, which depend closely on

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the island's coastal and marine resources [3].

The island supports a diverse range of marine and terrestrial life, including coral communities, seaweeds, fish, molluscs, birds and reptiles [4, 5]. Its beaches also provide nesting habitat for globally threatened sea turtles [5]. A 2022 survey of the island's terrestrial flora identified 78 plant species belonging to 40 families [6]. These habitats and species make the island ecologically valuable, while its small area and low-lying coastal setting increase its sensitivity to human pressures and environmental change.

Tourism and related development have added pressure to the island's land and coastal environments. A marine-litter survey identified tourism, local markets, hotels, household waste and fishing activities among the sources of litter recorded around the island [7]. Remote-sensing studies have documented changes in land use and land cover (LULC), including expansion of built-up areas and declines in vegetation cover [8, 9]. Coastal vegetation is also relevant to the island's resilience: research on Pandanus trees has assessed their capacity to reduce storm-surge risk [10]. Together, these findings show why changes in vegetation cover matter for both ecosystem condition and coastal protection.

Previous research has examined plant diversity [6], vegetation health using satellite imagery [11], and LULC change and tourism-related environmental change [8, 9]. Soil carbon has also been measured at selected sites and soil depths [12]. Therefore, the claim that carbon storage has never been estimated on Saint Martin's Island would be too broad. The studies reviewed for this introduction do, however, leave room for a spatially explicit, multi-date assessment linking vegetation and LULC transitions with ecosystem carbon stocks across the island.

This study aims to assess vegetation and LULC change on Saint Martin's Island and estimate the spatial distribution and change in carbon storage using satellite imagery and the InVEST Carbon Storage and Sequestration model. InVEST estimates carbon stocks by applying carbon-pool values to LULC classes [13]. By identifying land-cover transitions associated with carbon gains or losses, the study can provide evidence to support vegetation restoration and sustainable land management on the island.

2. Materials and Method

2.1. The Research Area

The study was conducted on Saint Martin's Island in Teknaf Upazila, Cox's Bazar District, Bangladesh. Locally known as *Narikel Jinjira*, the island lies in the northeastern Bay of Bengal and forms the southernmost part of Bangladesh. It is located between 20°34′–20°39′ N and 92°18′–92°21′ E, approximately 9 km south of the Cox's Bazar–Teknaf Peninsula and 8 km west of the northwestern coast of Myanmar, near the mouth of the Naf River [10, 14, 15]. The island is low-lying and nearly flat; an average elevation of approximately 2.5 m above mean sea level has been reported [14].

Published area estimates vary: Kayum *et al.* report approximately 3.4 km^2, while the UNDP environmental profile reports about 5.9 km^2 of island land and approximately 12 km^2 when surrounding rocky platforms are included [10, 15]. The island is elongated from north to south. Its principal sectors are Uttarpara in the north, Madhyapara in the central part, and Dakshinpara in the south; Golachipa is the narrow neck connecting Uttarpara and Madhyapara. Cheradia (also called Chera Dweep) lies at the southern end [14, 15]. Uttarpara is approximately 2,134 m long and 1,402 m wide. Madhyapara is about 1,524 m long and 518 m wide at its widest point. Dakshinpara is approximately 1,929 m long, with a narrow 1,890 m tail extending southeast and a maximum width of 975 m [14, 16]. The location of the study area is shown in Figure 1.

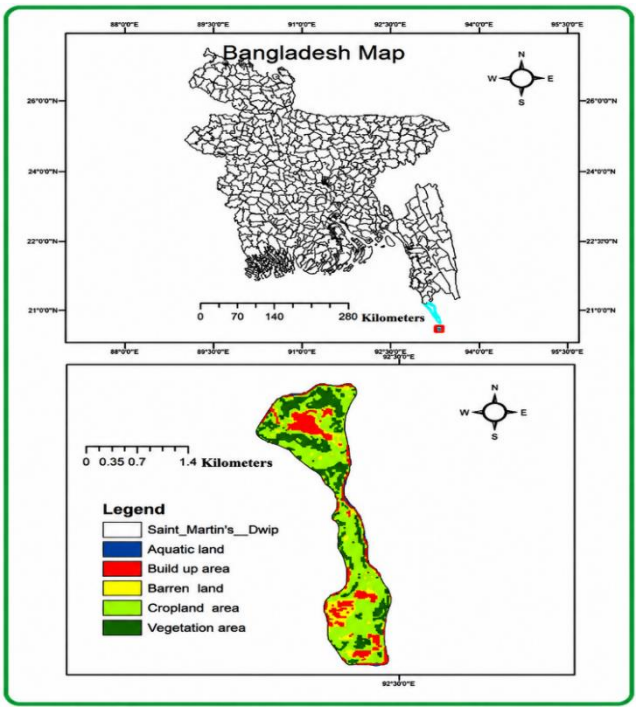


Figure 1. *Geographic location and Land Use/Land Cover (LULC) classification map of Saint Martin's Island, Bangladesh.*

In addition to the main Island there are a number of tiny islets ranging from 100 to 500 square meters are locally known as Chheradiadwip, which means separated island. Soil contains a huge amount of salt, and the seawater is the main source of salts. The range of pH value of soil is about 6.80 to 8.20. Soil is rich in $CaCO_3$. The maximum $CaCO_3$ is found in the lagoon area, and its range is between 2.20 and 9.40%. It is derived from different Mollusca animals.

2.2. Climatic Condition

Saint Martin's Island has a tropical monsoon climate moderated by its marine setting. Winter generally extends from mid-November through February, the pre-monsoon summer

from March to May, and the rainy season from June to October [6, 16]. Published estimates differ on the proportion of annual rainfall received during the monsoon: one source reports about 85%, while another reports more than 90% [6, 16]. October to February is described as mild and relatively dry [6].

One account report monthly mean temperature ranging from 15.8 ℃ in December to 26.2 ℃ in May. It also reports year-round high humidity, with a low of 70% in February and a high of 91% in June [6]. An earlier resource-mapping study reports different humidity values: 67% in February and 90% in July [17].

2.3. Vegetation

The study was conducted on Island, which is sandy area and the following species were recorded in the Island area such as: *Excoecaria agallocha, Pandanus furcatus, Nypa fruticans, Sonneratia apetala, Pongamia pinnata, Avecinia officianalis,* and *Casuarina equisetifolia* etc. Besides, the following tree species were also found as planted such as: *Cocos nucifera, Samanea saman, Mangifera indica, Aegle marmelos, Areca catechu, Azadirachta indica, Lagerstroemia speciosa, Swietenia mahagoni, Tectona grandis, Ziziphus mauritiana, and Erythrina fusca* etc.

2.4. Datasets

The data were collected through the ArcGIS software and Normalized Difference Vegetation Index (NDVI) technology. The research was conducted based on four Landsat satellite images captured at ten-year intervals between 1990 and 2020. At the initial stage, the types of data were Landsat 4-5 TM in 1990, 2000, and 2010, respectively. On the other hand, the last image source was Landsat 8-OLI sensor (Table 1). The research was conducted based on the 45 Datum WGS-84 zone, and clouds were less than 5% in all images.

Table 1. *Specifications and acquisition details of Landsat satellite imagery used in the study.*

Date of data obtained	Sensor	Cloud Cover	Path/Row
01/01/1990-12/31/1990	Landsat 4–5 TM Collection 2 Level 2	<5%	136/043
01/01/2000-12/31/2000	Landsat 4–5 TM Collection 2 Level 2	<5%	137/043
01/01/2010-12/31/2010	Landsat 4–5 TM Collection 2 Level 2	<5%	136/043
01/01/2020-12/31/2020	Landsat 8OLI/TIRS Collection 2 Level 2	<5%	136/043

Google Earth Engine (GEE) provides access to extensive satellite imagery and geospatial datasets, and supports large-scale image processing through Google's cloud computing infrastructure [18]. It has been used for land-use and land-cover (LULC) mapping and other satellite-based environmental analyses [19-22]. In this study, GEE was used to classify the study area into five LULC classes according to the criteria presented in Table 2.

Table 2. *Land Use and Land Cover (LULC) types, surface characterization, and corresponding color and index thresholds used for spatial classification.*

LULC type	Nature of land	Indicators
Water body	Different types of aquatic area such as rivers, canals, lakes, ponds permanent stagnant water etc.	Blue (0.015)
Build up Area	Residential, commercial, rural settlements, industrial infrastructure, transportation related infrastructure etc.	Red (0.14)
Barren land	Open space, bare land, exposed soil etc.	Yellowish (.018)
Low vegetation	Crop land, shrubs, playgrounds etc.	Light green (0.27)
Medium vegetation	Less tree than dense vegetation area	Medium green (0.36)
Dense vegetation	Trees and mixed forestland	Very green (>0.36)

For visual interpretation, Landsat 5 TM natural-color composites used bands 3–2–1, assigned to the red, green, and blue display channels, respectively; Landsat 8 OLI natural-color composites used bands 4–3–2. False-color infrared composites used TM bands 4–3–2 and OLI bands 5–4–3, with the near-infrared, red, and green bands assigned to the red, green, and blue channels, respectively [23]. These composites aid visual interpretation; NDVI is calculated separately from near-infrared and red reflectance as \((NIR-Red)/(NIR+Red)\). Accordingly, TM bands 4 and 3, and OLI bands 5 and 4, were used to calculate NDVI [23, 24]. Previous studies have applied Google Earth Engine (GEE) to LULC classification and land-cover change mapping [25-27]. In this study, NDVI change was assessed from the NDVI layers, while the Land Change Modeler (LCM) was used with categorical land-cover maps to quantify class transitions and model transition potential [28].

2.5. Estimation of Carbon Storage

The InVEST Carbon Storage and Sequestration model was used to estimate carbon storage associated with each LULC class, as in previous land use and carbon storage studies [31, 32]. For each class, the model estimates carbon stocks using four pools: aboveground biomass (C_a), belowground biomass (C_b), dead organic matter (C_d), and soil organic carbon (C_s) [13]. Carbon density for LULC class (i) was calculated as: total carbon stock across the study area was calculated as: where is the area of LULC class expressed in the same area unit used for the carbon density [13, 31]. InVEST reports carbon density in metric tons per hectare (t/ha). To report it in tons per square kilometer (t/km^2), the values must be multiplied by 100 [13].

$$C=\sum Am*(C_a+ C_b+C_s+ C_d)$$

Data were collected from field visits and five types of sampling were shown in the following table (Table 3). Carbon sequestration Model was established by analyzing the net change in pixel-by-pixel carbon storage between existing and future LULC maps based on years.

Table 3. *Carbon concentration (density in tons per square kilometer(t/km^2)) across four carbon pools (C_a, C_b, C_s, and C_d) for different Land Use and Land Cover (LULC) classes (Water body, Vegetation land, Built up, Crop land, and Bare land).*

LULC class	Carbon density ton per square kilometer (t/km^2)				References
	C_a	C_b	C_s	C_d	
Water body	0	0	11900	123	[32]
Vegetation land	410	5640	22600	22	[33]
Built up	210	4510	11530	27	[34]
Crop land	4650	8070	10840	100	[35]
Bare land	2260	9030	14660	294	[30]

3. Results and Discussion

3.1. Changing Patterns of Vegetation with LULC

The present research was conducted on Saint Martin's Island for the determination of vegetation degradation and carbon storage patterns from 1990 to 2020 using NDVI, LULC, and the InVEST model etc. Land Use and Land Cover (LULC) shows that aquatic area, vegetation area, built up area, cropland area, and barren land area fluctuated from 1990 to 2020 due to various biotic and abiotic interferences. The findings of the research revealed that the total area of Saint Martin's Island is 3.17 square kilometers and the total area classified in five groups through the spatiotemporal picture (Figure 2). The aquatic land area, vegetation area, built up area, cropland area, and barren land area are expressed through blue, green, red, light green, and yellow respectively (Figure 2).

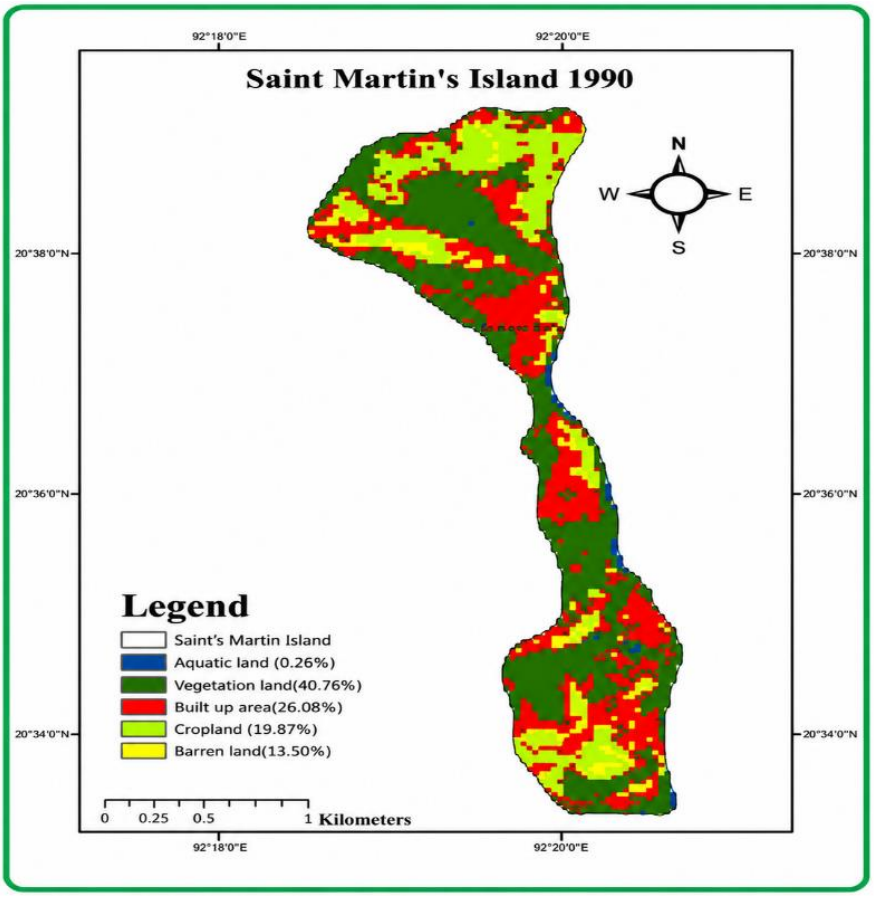


Figure 2. *Spatial distribution of Land Use and Land Cover (LULC) classes across Saint Martin's Island in 1990.*

The aquatic, vegetation, build up, cropland, and barren land area were 0.95%, 39.75%, 25.88%, 19.87%, and 13.55% in 1990, respectively (Figure 3).

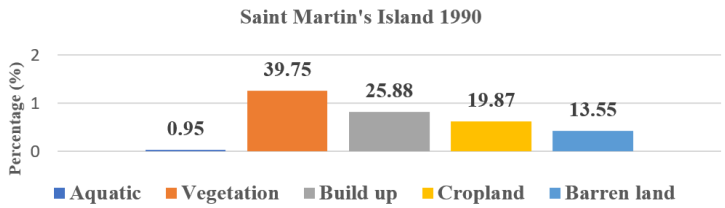


Figure 3. *Land cover patterns of Saint Martin's Island in 1990.*

The spatiotemporal picture predicts that there is a great diference between 1990 and 2000, which is expressed in different colors. The land criteria changed through different interferences, and build up area, and cropland area increased and aquatic land area, vegetation, and barren land area decreased due to overgrowth population in the whole area of Saint Martin's Island (Figure 4).

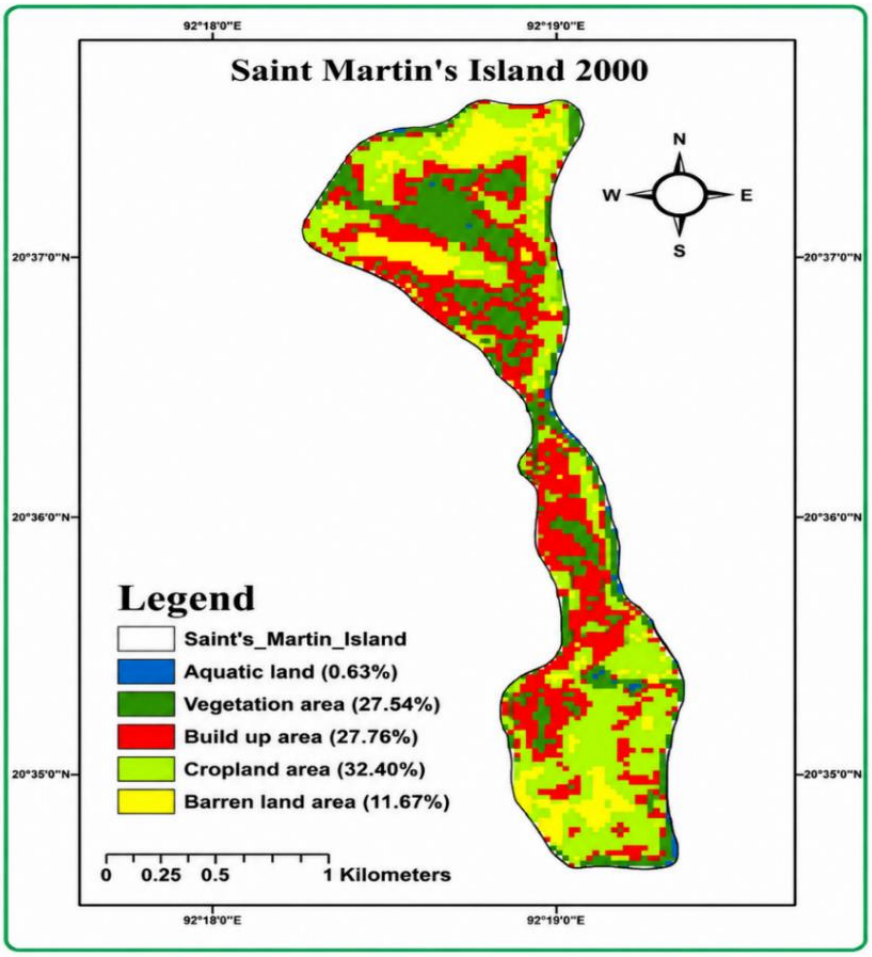


Figure 4. *Land Use/Land Cover (LULC) map of Saint Martin's Island in the year 2000.*

The aquatic, vegetation, build up, cropland, and barren land area were 0.63%, 37.54%, 27.76%, 22.40%, and 11.67% in 2000, respectively (Figure 5). The build up area, and cropland area increased 1.88% and 2.53% respectively from 1990 to 2000. At that time, the aquatic land area, vegetation area, and barren land area decreased 0.32%, 2.21%, and 1.88% in 2000 respectively.

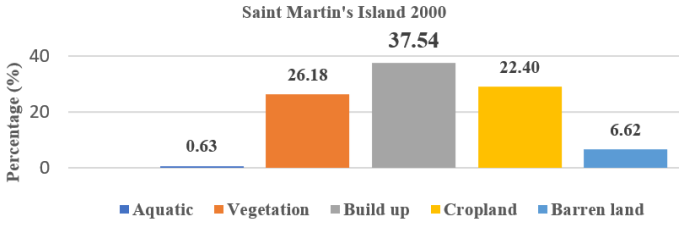


Figure 5. *Land cover distribution of Saint Martin's Island in 2000. Bar chart illustrating the percentage distribution across five distinct land cover categories.*

The spatiotemporal picture indicates that the maximum changing patterns of vegetation between 2000 and 2010. The blue, red and light green colors increased from 2000 to 2010, while green and yellow colors decreased in the same period of the study area (Figure 6).

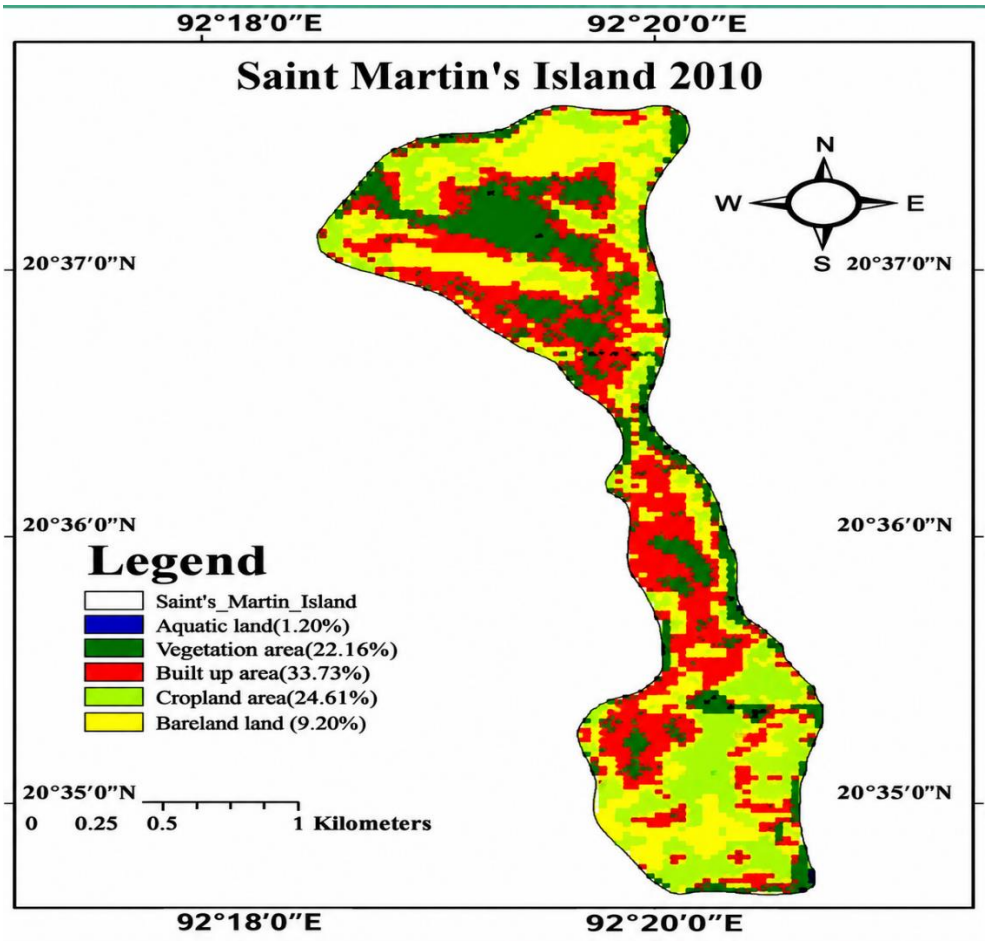


Figure 6. *Land Use and Land Cover (LULC) classification map of Saint Martin's Island in 2010.*

The aquatic, vegetation, build up, cropland, and barren land area were 1.26%, 32.18%, 33.75%, 24.61%, and 8.20% in 2010 respectively (Figure 7). The aquatic land area, build up area, and cropland area increased 0.63%, 5.99% and 2.21% respectively from 2000 to 2010. While the vegetation area and barren land area decreased 5.36% and 3.47% respectively.

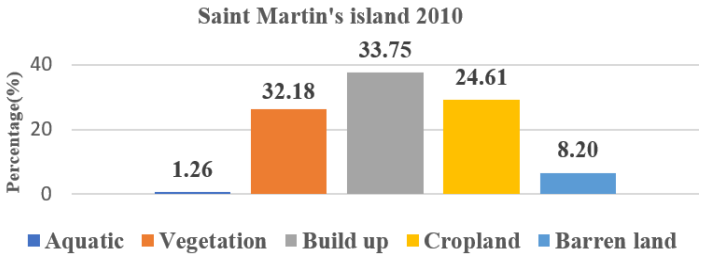


Figure 7. *Quantitative distribution of Land Use and Land Cover (LULC) classes for Saint Martin's Island in 2010.*

The vegetation is always changed in the study area which expressed in different spatiotemporal pictures. Natural and environmental conditions are degraded with changing of vegetation of the study area. The spatiotemporal picture indicates that vegetation changed in 2020 than 2010, which is expressed in the following figure (Figure 8).

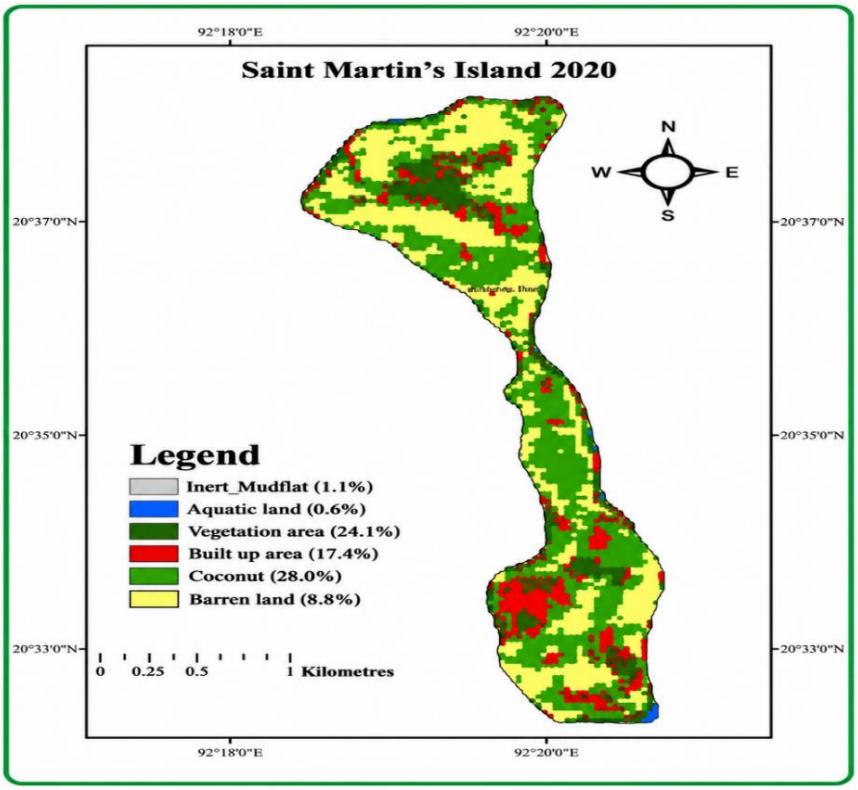


Figure 8. *Land Use and Land Cover (LULC) Map of Saint Martin's Island (2020).*

The aquatic, vegetation, build up, cropland, and barren land area were 0.63%, 26.18%, 37.54%, 29.03%, and 6.62% in 2020 respectively (Figure 9). The aquatic land area, vegetation area, and barren land decreased 0.63%, 6.00%, and 1.58% from 2010 to 2020 respectively. On the other hand, build up area and cropland area increased 3.795 and 4.42% in 2020 respectively.

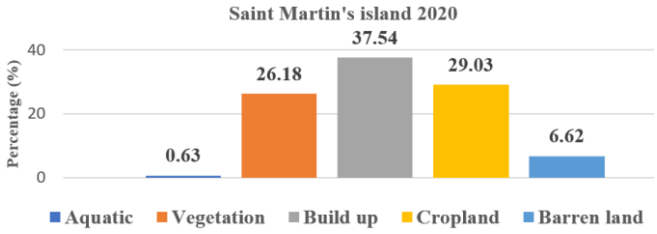


Figure 9. *Land use and land cover (LULC) distribution percentage of Saint Martin's Island in 2020.*

The total aquatic land area, vegetation area, build up area, cropland area, and barren land area were 0.95% 39.75%, 25.88%, 19.87%, and 13.55% in 1990 respectively. In this case, the build up area, and cropland area increased 11.66% and 9.16% respectively from 1990 to 2020. The maximum built up area increased from 2010 to 2020. On the other hand, the aquatic land area, vegetation area, and barren land area decreased 0.032%, 13.57%, and 6.93 respectively from 1990 to 2020. The maximum vegetation decreased from 2010 to 2020. The maximum built up area increased from 2010 to 2020. The aquatic land and barren land gradually decreased from 1990 to 2020, but the aquatic land also increased from 1990 to 2000. The findings of the research indicate that build up area increased more than other land criteria due to overgrowth of population. The total land criteria of the research area also fluctuated due to natural calamity such as cyclone, Aila and Sidr in 1991, 2009, and 2014. Actually, the research area is the most important tourist hotspot of Bangladesh. There are many temporal huts, hotels, and motels for the recreation of tourists, which is the major cause of degradation of vegetation in Saint Martin's Island.

3.2. Variations of Carbon Storage

The total area of Saint Martin's lsland is 3.17 square kilometers and carbon was also stored in different pools such water, vegetation, built up, cropland and barren land area etc. The findings revealed that about 0.04×10^4, 3.90×10^4, 1.43×10^4,

1.39×10^4 and 0.21×10^4 (Mg) were found in aquatic, vegetation, built up, cropland, and barren land area respectively in 1990 (Table 4). The total carbon of water was 0.04×10^4, 0.02×10^4, 0.05×10^4 and 0.02 (Mg) in 1990, 2000, 2010 and 2020 respectively (Table 4). About 0.02×10^4, 0.03×10^4 and 0.03×10^4 (Mg) of water carbon declined in 2000, and 2020 respectively. The research indicated that the water area 0.63% increased from 2000 to 2010. The vegetation carbon was about 3.90×10^4, 3.02×10^4, 2.65×10^4, and 2.12×10^4 (Mg) in 1990, 2000, 2010, and 2020 respectively (Table 4). The vegetation carbon gradually decreased 0.88×10^4, 0.37×10^4 and 0.53×10^4 (Mg) from 1990 to 2020. The maximum vegetation carbon decreased from 1990 to 2000. Alam et al. reported that Saint Martin's Island had lost roughly 25% of its coral reef over the preceding seven years; the authors also described coral removal for sale and unplanned, unregulated tourism as pressures on the island's ecosystem [14].

There is always a positive relationship between carbon source and carbon sink, which is expressed through the present research. The built-up carbon was 1.43×10^4, 1.59×10^4, 1.69×10^4, and 1.85×10^4 (Mg) in 1990, 2000, 2010, and 2020 respectively (Table 4). The build up carbon gradually increased due to increase the build up area. The built-up carbon increased 0.16×10^4, 0.10×10^4, 0.16×10^4 (Mg) in 2000, 2010, and 2020 respectively. The lowest build up carbon increased from 2000 to 2010.

Table 4. *Changing patterns of carbon storage of Saint Martin's Island from 1990 to 2020.*

LULC types	1990	2000	2010	2020
	Carbon storage (Mg)	Carbon storage (Mg)	Carbon storage (Mg)	Carbon storage (Mg)
Aquatic area	0.04×10^4	0.02×10^4	0.05×10^4	0.02×10^4
Vegetation	3.90×10^4	3.02×10^4	2.65×10^4	2.12×10^4
Built up area	1.43×10^4	1.59×10^4	1.69×10^4	1.85×10^4
Crop land area	1.39×10^4	1.31×10^4	1.12×10^4	1.03×10^4
Barren land area	0.21×10^4	0.11×10^4	0.09×10^4	0.07×10^4
Total CS	6.97×10^4	6.05×10^4	5.60×10^4	5.09×10^4

The cropland carbon was 1.39×10^4, 1.31×10^4, 1.12×10^4, and 1.03×10^4 (Mg) in 1990, 2000, 2010, and 2020 respectively (Table 4). The declination of cropland carbon was 0.08×10^4, 0.19×10^4, and 0.09×10^4 (Mg) in 2000, 2010, and 2020 respectively. In this case, the highest declination found between 2000 and 2010. The barren land carbon was 0.21×10^4, 0.11×10^4, 0.09×10^4, and 0.07×10^4 (Mg) in 1990, 2000, 2010, and 2020 respectively (Table 4). The decreasing of baren land carbon was 0.10×10^4, 0.02×10^4, and 0.02×10^4 (Mg) in 2000, 2010, and 2020, respectively. The highest declination was found between1990 and 2000. The total carbon storage was 6.97×10^4, 6.05×10^4, 5.60×10^4, and 5.09×10^4 (Mg) found in 1990, 2000, 2010, and 2020 respectively at Saint Martin's Island under Teknaf upzila of Cox's Bazar district in Bangladesh (Table 4).

The total carbon decreased 0.92×104, 0.45×104, and 0.51×104 (Mg) from 1990 to 2000 and the highest decreased between 1990 and 2000. Tourism-related development is a documented pressure on Saint Martin's Island. A study of land-use and land-cover change from 2005 to 2019 found more frequent changes in areas with higher tourist pressure; resort and hotel construction increased while agricultural land declined [1, 36]. The 2017 Rohingya influx was associated with forest and vegetation loss around refugee settlements in Teknaf [37]. Because that evidence concerns the Teknaf mainland, it should not be treated as direct evidence that the influx caused vegetation or carbon loss on Saint Martin's Island. Carbon storage varies across land-cover types, as studies in coastal Bangladesh have demonstrated changes in ecosystem carbon storage associated with plantation forest development [29], while other studies have reported higher carbon stocks in dense forests and positive relationships between stand structural diversity and aboveground carbon storage [38, 39]. Forest fragmentation and edge effects can also reduce soil carbon [40]. Therefore, vegetation loss or conversion to built-up land may reduce carbon storage on Saint Martin's Island; the amount should be estimated from the Island's land-cover areas and the carbon densities assigned to aboveground biomass, belowground biomass, dead organic matter, and soil pools [35, 38]. Vegetation change and land-management practices can also affect carbon sequestration and related ecosystem services [35, 41]. These findings support stronger land-use planning and controls on unregulated tourism and physical development on this environmentally sensitive island [1, 36].

4. Conclusion

Saint Martin's Island is the only fringing coral Island in Bangladesh. The research was conducted on Saint Martin's Island for the determination of changing vegetation and its impact on carbon storage. The findings help to understand the degradation of vegetation and also indicate the significance of sustainable land management and conservation strategies. Overall, the findings of the research will be helpful to researchers' scientists, administrators, and policymakers for the conservation of natural resources without changing land use patterns and for conserving the natural ecosystem. The research indicates that there is a positive relationship between degradation of vegetation and carbon storage in Saint Martin's Island. But unfortunately, the whole biodiversity is changed due to the over tourism' activities. About 50% of trees were cut down in only one decade through human interference. The Island is rich in flora and fauna and is the most suitable habitat for some threatened turtle species in the world. The findings indicated that vegetation and carbon storage declined at a geometrical rate due to infrastructural development and over tourism, which leads to loss of biodiversity in Saint Martin's Island. The policymakers and administrators should raise awareness among the community, tourists, and local people to conserve the biodiversity of the Island. The local authority should promote ecotourism-based activities and ban all commercial tourism. Conservation strategy, coastal zone management, and impact assessment monitoring will also be developed for the protection of the unique Island of Bangladesh.

Abbreviations

GEE	Google Earth Engine
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
LCM	Land Change Modeler
LULC	Land Use and Land Cover
NDVI	Normalized Difference Vegetation Index
NIR	Near-Infrared
OLI	Operational Land Imager
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
UNDP	United Nations Development Programme
WGS-84	World Geodetic System 1984
CS	Carbon Storage (used in "Total CS" in Table 4)
Mg	Megagram (metric tonne; 1 Mg = 1,000 kg)
t/ha	Metric Tonnes per Hectare
t/km^2	Metric Tonnes per Square Kilometer
C_a (Ca)	Carbon Stock in Aboveground Biomass
C_β (Cb)	Carbon Stock in Belowground Biomass
C_s (Cs)	Carbon Stock in Soil Organic Carbon
C_d (Cd)	Carbon Stock in Dead Organic Matter
A_m (Am)	Area of Land-use/land-cover Class m (as used in the carbon-stock equation)

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Author Contributions

Mohammed Mukhlesur Rahman: Data curation, Formal Analysis, Investigation, Methodology, Software, Visualization, Writing – original draft

Sabrina Naz: Conceptualization, Methodology, Supervision, Validation, Writing – review & editing

Nurul Hamid: Conceptualization, Formal Analysis, Investigation, Project administration, Resources, Software, Visualization, Writing – original draft

Md. Redwanur Rahman: Conceptualization, Data curation, Methodology, Supervision, Validation, Writing – review & editing

Data Availability Statement

All data were the secondary sources. Data are available to the corresponding author. After accepting it will be provided if journal needed.

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography



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