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Spatio-Temporal Changes of St. Martin Island from 2005 to 2023

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ABSTRACT

St. Martin Island has changed over the past years, with booming tourism replacing agricultural land and altering landscapes. This study investigates the land use and land cover changes on the island, spanning the years from 2005 to 2023. Using Landsat 5, Landsat 8, and Sentinel 2 imagery alongside remote sensing and GIS technologies, landuse maps were generated for 2005, 2015, and 2023. Emphasizing the accuracy assessment and validation processes, the study reveals substantial transformations in this island's landscape. The key findings highlight a rapid expansion of built-up areas (17.73%), especially in the northern regions, driven by the increasing coastal tourism. Concurrently, agricultural land has dwindled (3.87%), reflecting changing land use practices and priorities. Vegetation exhibited dynamic fluctuations (increased by 3.17%), influenced by urbanization and reforestation. These changes have environmental implications. Including, potential habitat disruption and ecological consequences. Recommendations include sustainable tourism planning, agricultural preservation, vegetation restoration, careful infrastructure development, data monitoring, and community engagement. The proposed strategies aim to balance the island's economic development with ecological sustainability, ensuring St. Martin Island's long-term vitality.

Keywords: LULC Change, change detection, GIS analysis, St. Martin Island, Urbanization

1. INTRODUCTION

Bangladesh has an attractive natural environment with many historical-cultural places. It is bestowed with beautiful coasts and beaches, archaeological sites, historical and religious places, hills and islands, forests etc. (Rahman et al., 2010). It attracts foreign and domestic visitors and generate revenues, including foreign exchanges earnings in Bangladesh. (Spalding et al., 2017a). The coastal tourism industry has emerged as a significant economic driver in many tropical countries, including Bangladesh. However, its rapid growth is a threat to natural re-sources and ecology, particularly in St. Martin Island, Cox's Bazar. Despite being a major tourist attraction, the island's fragile ecosystem, including coral reefs, vegetation, and agricultural land and other landscapes including beach areas (Bhuyan et al., 2019) faces degradation due to the alarming decline of coral resources and changes in land and land cover patterns.

Research conducted by Islam et al. (2016) and Gazi et al. (2021) has highlighted the alarming decline of coral resources and the degradation of coral reef ecosystems due to anthropogenic interventions such as tourism, coral extraction, and overfishing. Furthermore, studies by Ahmed et al. (2023) and Hossen and Sultana (2023) have documented significant changes in land use and land cover patterns including the expansion of built-up area and the encroachment on terrestrial habitats.

Despite these insights, there remains a notable gap in understanding the specific impacts of coastal tourism on vegetation and agricultural land on St. Martin Island. This study aims to address this gap by quantifying the rates of land cover change, particularly focusing on built-up area, vegetation, and agricultural land. Additionally, it seeks to investigate the correlation between the rate of built-up area expansion and changes in vegetation and agricultural land, shedding light on the broader environmental implications of coastal tourism.

Conducting a thorough analysis of spatio-temporal changes on St. Martin Island aims to provide valuable insights for policymakers, environmentalists, and other stakeholders. Ultimately, these findings will contribute to the formulation of evidence-based management strategies aimed at promoting sustainable tourism development and preserving the ecological integrity of St. Martin Island for future generations.

This study aims to contribute to the understanding of the environmental impacts of coastal tourism on St. Martin Island, Cox's Bazar, Bangladesh, by addressing specific objectives: 1) to quantify the land cover change rate of built-up area, 2) to measure the land cover change rate of vegetation and agricultural land, and 3) to find out the correlation between land cover change rate of built-up area, and vegetation and agricultural land.

2. MATERIAL AND METHODS

2.1 Study area

The Saint Martin's island presents a variety of physiographic features, namely; rocky platform, sandy beach, sand dune, lagoon, marshes, tombolo, crenulated shoreline, and coral clusters (Muhibbullah and Sarwar, 2017). Approximately seven thousand people were nested and a large number of tourists rest (Afrin et al., 2013) at the small island of 3 km² in the north-eastern part of the Bay of Bengal, about 9 km south of the tip of the Cox's Bazar-Teknaf peninsula, and forming the southernmost part of Bangladesh. The island had seven local administrative areas, which are locally known as "Para". They were Uttar Para, Pashchim Para, Purbo Para, Maddham Para, Kona Para, Golachipa, Dakshin Para, and Pug Kata Bonia (Figure 1). It is 1.8 km long and a rocky reef comprises three small vegetated islands of which the middle one was the larger in area (Ara et al., 2021).

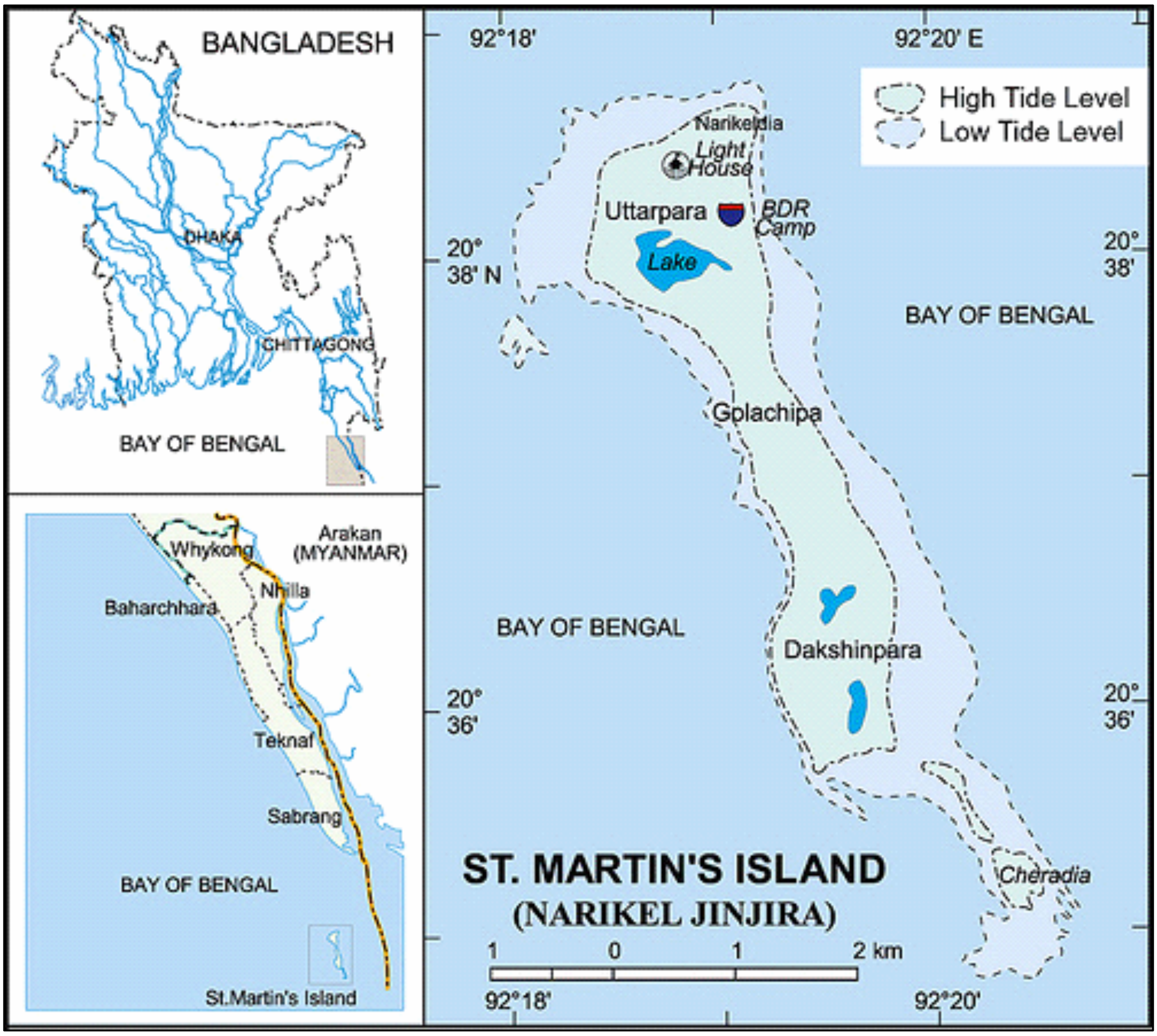


Figure 1: St. Martin Island (Siddiqui et al. 2016)

2.2 Data

2.2.1 Satellite Imagery

Satellite imagery from Landsat 5 TM, Landsat 8 OLI, and Sentinel-2 was utilized to capture the geographical features of St. Martin Island. Landsat data, with a spatial resolution of 30 meters, and Sentinel-2 data, offering higher resolution at 10 meters, provided multispectral data crucial for land cover analysis. These satellites operate on sun-synchronous orbits, enabling regular image acquisition and facilitating the monitoring of land cover changes over time.

To fulfil the objectives of the study, satellite images from May 2005, June 2015, and May 2023 were acquired for St. Martin Island. The study area was delineated writing Landsat path 135 and row 46, utilizing the UTM projection system. Before land use and land cover mapping, standard radiometric and atmospheric corrections were applied to ensure data accuracy and consistency.

2.3 Methods and Techniques

Basically, this study focused on understanding Land Use and Land Cover (LULC) changes over the years 2005 to 2023. It begins by collecting satellite images from reliable sources like Landsat 5 TM, Landsat 8 OLI, and Sentinel 2. These images were then preprocessed through atmospheric correction, cloud masking, and geometric correction to ensure they were accurate and ready for analysis.

The next step involved supervised image classification, where the land was categorized into different classes, such as built-up areas, vegetation, and agricultural land. Using this data, LULC maps were created for 2005, 2015, and 2023 to visualize how land use has changed over time. To ensure the reliability of these maps, accuracy assessments were conducted using tools like the Semi-automatic Classification Plugin (SCP), HCMGIS, Google Earth Pro, and Kappa's Formula.

The study also investigated the correlation between land use and land cover changes, alongside calculating the rate of changes in different categories over the years. Area measurements were carried out using GRASS GIS and SCP, providing insights into the extent of land-use transformations. Moreover, change detection analyses are performed to compare shifts in LULC during the period. Finally, all the findings were visually represented, making it easier to understand and interpret the landscape changes that have occurred over almost two decades. These methods and steps were summarized and visually represented in Figure 2.

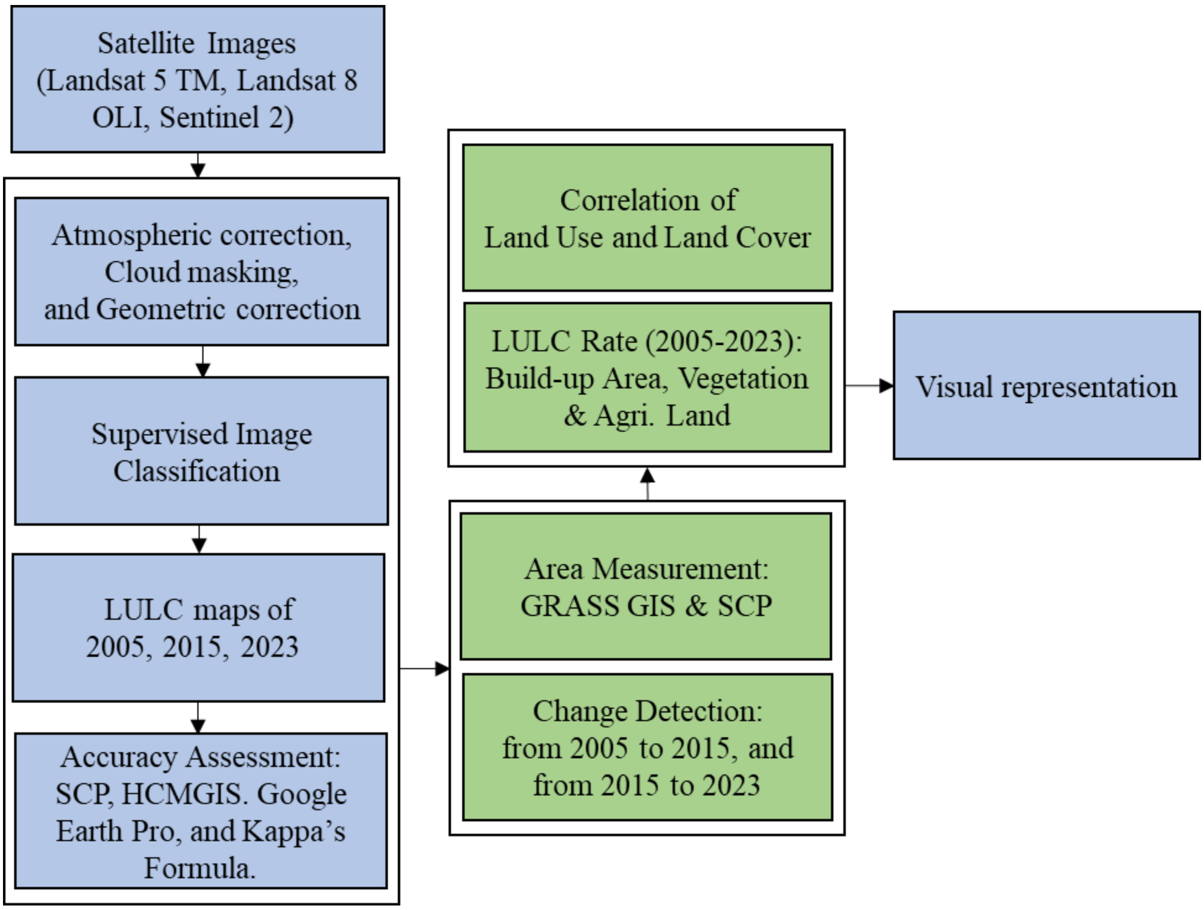


Figure 2: Framework of the study

2.3.1 Satellite Image Analysis

Supervised classification, a machine learning technique, was employed to categorize pixels within the satellite imagery into predefined land cover classes. This involved collecting truth-training data for classes such as vegetation, built-up areas, agricultural land, sandy beaches, and coral reefs, where vegetation consists of areas blanketed by various trees, contributing to the island's natural ecosystem. Agricultural land denotes cultivable expanses, with or without crops, located in inland regions where farming activities take place. Built-up areas represent developed zones characterized by buildings and other infrastructure. Water bodies include ponds, canals, and the expansive Bay of Bengal. Sandy beaches and coral reefs adorn the is-land's coastline, offering picturesque sandy shores and a vibrant underwater ecosystem unique to St. Martin Island. Google Earth Engine, a cloud-based geospatial platform, facilitated supervised classification and customization of classes based on study requirements.

The supervised image classification algorithm used in this study follows a structured process to generate land cover maps for St. Martin Island for the years 2005, 2015, and 2023. Initially, satellite images from Landsat 5, Landsat 8, and Sentinel 2 were acquired and preprocessed by filtering for specific time frames, cloud cover, and clipping to the region of interest. Training data was prepared by collecting labeled points representing distinct land cover types such as water, built-up areas, vegetation, coral reefs, and agriculture. These labeled points were merged into a single feature collection. Relevant spectral bands, such as B2 (blue), B3 (green), and B4 (red) were selected from the images to extract features for classification. A supervised classifier, specifically the smileCart decision tree algorithm, was trained using the labeled training data to predict land cover classes. The trained classifier was applied to the image to generate a classified where each pixel was assigned a specific land cover type. Validation of the classification was conducted by comparing the classified results against independent validation data, and accuracy metrics, such as the error matrix and overall accuracy, were computed. The final classified maps were exported for visualization and analysis, with each land cover type represented by a unique color: cyan for water bodies, red for built-up areas, green for vegetation, pink for coral reefs, and yellow for agriculture.

2.3.2 Accuracy Assessment

One of the most important steps at classification process is accuracy assessment. The accuracy assessment is to quantitatively assess how effectively the pixels were sampled into the correct land cover classes. (Rwanga and Ndambuki, 2017). An accuracy assessment was conducted to evaluate the quality and reliability of the classified land cover map. Semi-automatic Classification Plugin in Quantum GIS enabled accuracy assessment by comparing classified pixels with ground truth data. Producer's and user's accuracy measures were employed to assess errors of omission and commission, ensuring the accuracy of classification outcomes. The overall accuracy of the map of 2005, 2015, and 2023 was calculated using the following equation.

$$Overall\ Accuracy = \frac{Total\ number\ of\ correctly\ classified\ samples}{Total\ number\ of\ samples} \quad (1)$$

The overall accuracy of the map of 2005, 2015, and 2023 was 88.44%, 92.63%, and 95.67% respectively. The value of Kappa hat classification of the map of 2005, 2015, and 2023 was calculated also using Eq. (2).

$$Kappa = \frac{(total\ accuracy - random\ accuracy)}{(1 - random\ accuracy)} \quad (2)$$

2.3.3 Post-classification Area Measurement & Change Detection

Change detection analyses describe and quantify differences between images of the same scene at different times (Hegazy and Kaloop, 2015). Post-classification comparison change detection was utilized to detect land cover changes between different periods. This involved classifying rectified images from two periods separately and comparing them to identify changes in land cover types such as built-up areas, vegetation, and agricultural land.

$$Change_{ij} = C_{ij}^{t2} - C_{ij}^{t1} \quad (3)$$

Where, C_{ij}^{t1} is the classification of the pixel at location (i, j) at time $t1$. C_{ij}^{t2} is the classification of the pixel at location (i, j) at time t2. $Change_{ij}$ indicates whether a change has occurred at location (i, j).

The area of land cover classes was measured using GRASS GIS's 'r.report' command, allowing for the quantification of land cover changes over time. equation 4 was used to calculate the area, which is the general formula for measuring the area.

Area = Number of Pixels in Class × Area per Pixel (4)

This facilitated the analysis of correlations between different land cover types and provided insights into land use dynamics.

2.3.4 Correlation of Land Use and Land Cover Types

Correlation analysis was conducted to establish relationships between land uses and cover types, particularly focusing on the impact of built-up area development on vegetation and agricultural land. Graphical representations were utilized to visualize these relationships and interpret the findings effectively.

3. RESULT AND DISCUSSION

St. Martin island, located in the Bay of Bengal near the southeastern coast of Bangladesh, is the country's only coral island. Covering area of about 3 sq. kms. The island's landmass is small, with most of it being low-lying. The land has been subject to erosion, particularly due to rising sea levels and human activities. Over time, the island's size has decreased. Leading to concerns about its long-term variability.

The surrounding waters are clear and support a diverse marine ecosystem. However, water quality has been deteriorating due to pollution from tourism and other human activities. Efforts to preserve the water quality have been initiated, but challenges remain in effectively managing the growing number of visitors and their impact on the environment.

The island's vegetation is a mix of tropical plants, including coconut palms, screw pines, and various shrubs. Unfortunately, much of the original vegetation has been cleared for tourism development and conservation is delicate.

St. Martin Island is home to Bangladesh's only coral reef, which is vital for marine biodiversity. The reef supports various species of fish, mollusks, and other marine life. However, the coral reef is under significant stress due to climate change, pollution, and unregulated tourism. Conservation programs are in place, but the reef remains in a vulnerable state.

St. Martin Island is a unique ecological treasure that faces significant environmental challenges. While it remains a popular tourist destination, sustainable management is crucial to preserving its natural beauty and biodiversity for future generations.

3.1 Changes in Built-up area (2005-2023)

The land use and land cover pattern had changed gradually from 2005 to 2023, both in the northern and southern part of the island. Built-up area rose from 0.035 square kilometers in 2005 to 0.247 square kilometers in 2015. (Figure 3, Table 1). Following 2015, the built-up area increased drastically to 0.567 square kilometers in 2023.

The frequency of tourist visits in 2005 was very low due to the lack of tourist-friendly infrastructures. Tourists used to stay there in tents to experience the beauty of the coral island. As coastal tourism increased on that particular island, the stakeholders and business companies started to build hotels, motels, restaurants, roads, ferry ghats, and other infrastructures to comfort and amuse the tourists. Mostly the infrastructures were built in the northern part of the island. A road named 'Bangla Boss Road' was built to connect the southern part of the island after 2005.

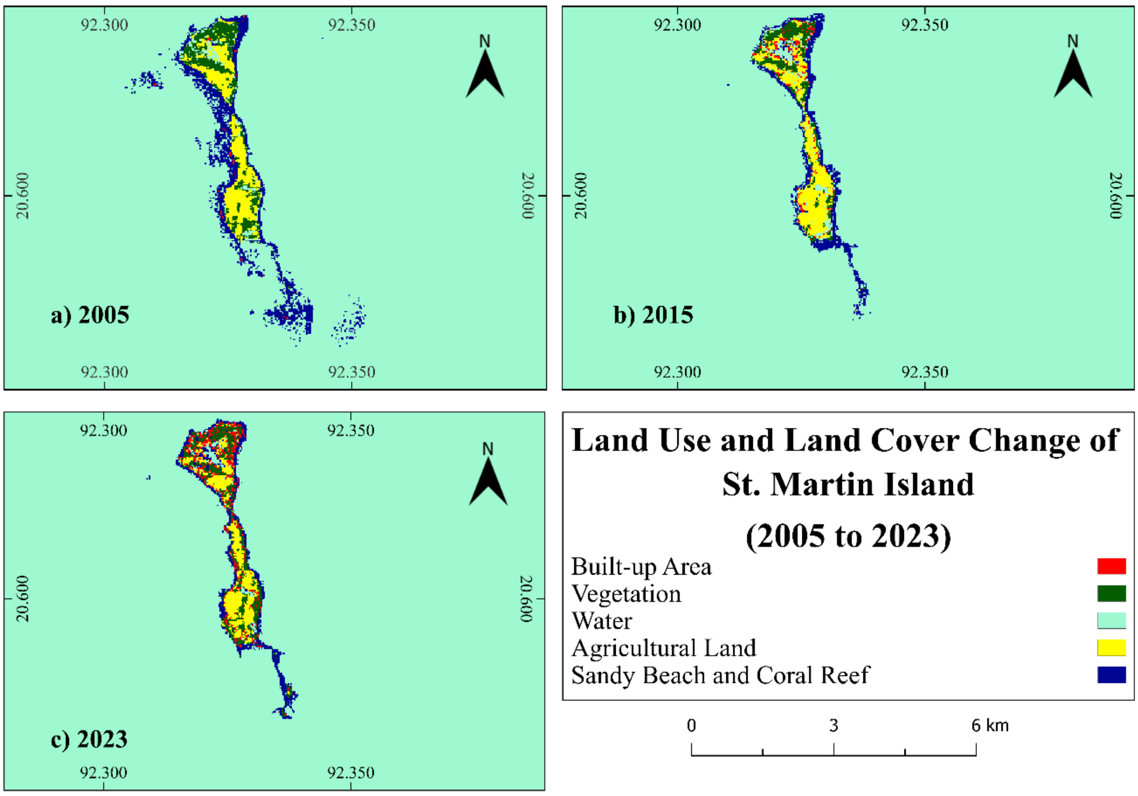
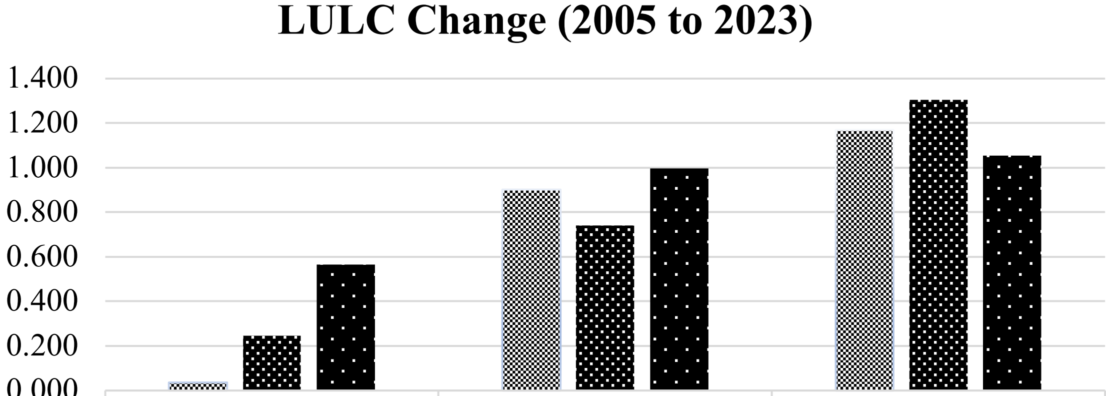


Figure 3: Land use and land cover change of St. Martin Island (2005 to 2023).



	Built-up Area	Vegetation	Agriculture
2005	0.035	0.901	1.170
2015	0.247	0.740	1.303
2023	0.567	0.996	1.054

Figure 4: LULC change (2005 to 2023)

Table 1: Calculation of land cover change rate

Calculation of Land Cover Change Rate (2005-2015)					
Class	**Total Area (in sq. km)**	**2005 (in sq. km)**	**2015 (in sq. km)**	**Change (in sq. km)**	**Change Rate (%)**
Built-up Area	3	0.035	0.247	0.212	7.07
Vegetation		0.901	0.74	-0.161	-5.37
Agri. Land		1.17	1.303	0.133	4.43
Calculation of Land Cover Change Rate (2015-2023)					
Class	**Total Area (in sq. km)**	**2015 (in sq. km)**	**2023 (in sq. km)**	**Change (in sq. km)**	**Change Rate (%)**
Built-up Area	3	0.247	0.567	0.32	10.67
Vegetation		0.74	0.996	0.256	8.53
Agri. Land		1.303	1.054	-0.249	-8.30
Calculation of Land Cover Change Rate (2005-2023)					
Class	**Total Area (in sq. km)**	**2005 (in sq. km)**	**2023 (in sq. km)**	**Change (in sq. km)**	**Change Rate (%)**
Built-up Area	3	0.035	0.567	0.532	17.73
Vegetation		0.901	0.996	0.095	3.17
Agri. Land		1.17	1.054	-0.116	-3.87

However, there was only 0.035 square kilometers of built-up area or other tourist-friendly infrastructure until the study period in 2005. The southern part of the island was mostly agricultural land and vegetation. The amount of built-up area increased up to 7.07% (Table 1) from 2005 to 2015.

It was observed that, from 2015 to 2023, local people, the stakeholders and the business companies started to build settlements and resorts commercially all over the island 10.67% (Table 1) faster, including in the southern part of the island.

3.2 Changes in Agricultural land and Vegetation (2005-2023)

The total area of agricultural land was 1.17 square kilometers, along with 0.901 square kilometers vegetation covering most of the island in 2005. During the next decade, from 2005 to 2015, agricultural land increased to 1.303 square kilometers, while the vegetation decreased at 0.740 square kilometers. Until 2015, most of the island was covered by agricultural land and vegetation. In the year of 2023, the amount of agricultural land dropped down to 1.054 square kilometers and vegetation dramatically rose to 0.996 square kilometers. (Figure 3, Table 1).

According to the area measurement of the map of St. Martin Island 2005, 2015, and 2023, it was observed that agricultural land and the vegetation in the island was in an unstable condition. In 2005, when there were limited tourists on the island, the whole island was covered with agricultural land and vegetation both in the northern and southern parts of the island before the beginning of the infrastructure development period. After the growth started, the agricultural land began to decrease day by day.

From 2005 to 2015 the vegetation-covered area was reduced 5.37% and agricultural land was increased to 4.43% (Table 1) due to the local population's need to expand agricultural activities for their livelihoods. To meet the demands of tourists, there was a greater emphasis on producing vegetables and fruits locally.

It was observed that, from 2015 to 2023, They planted trees around their settlement and especially, "Keya ful" (Pandanus tectorius) in the surrounding of the resorts, restaurants, and roads, which was responsible for the growth of vegetation. In the year of 2020, tourism was halted by the Government of Bangladesh in the island due to COVID-19 pandemic situation on-going in the country, which helped the vegetation to grow naturally without any human disturbance.

3.3 Correlation of Land Cover Change Rate between Built-up Area, and Vegetation and Agricultural land

In the time span of 2005 to 2015, the built-up area and agricultural land was increased to 7.07%, and 4.43%, while vegetation was dropped down for 5.37%. In the next decade, 2015 to 2023, the built-up area increased 10.67%, along with vegetation (8.53%). On the other hand, agricultural land decreased to 8.30%. (Table 1).

The overall change rate during the study period from, 2005 to 2023, shows that the Built-up Area had increased by 17.73% in that small island of three square kilometres, while vegetation had only increased by 3.17% which makes the condition of vegetation on the island unstable. It can hamper the ecological system of the island. On the other hand, due to the rapid growth rate of coastal tourism and Built-up Area, the agricultural land had gradually decreased by 3.87% during the study period (Figure 5).

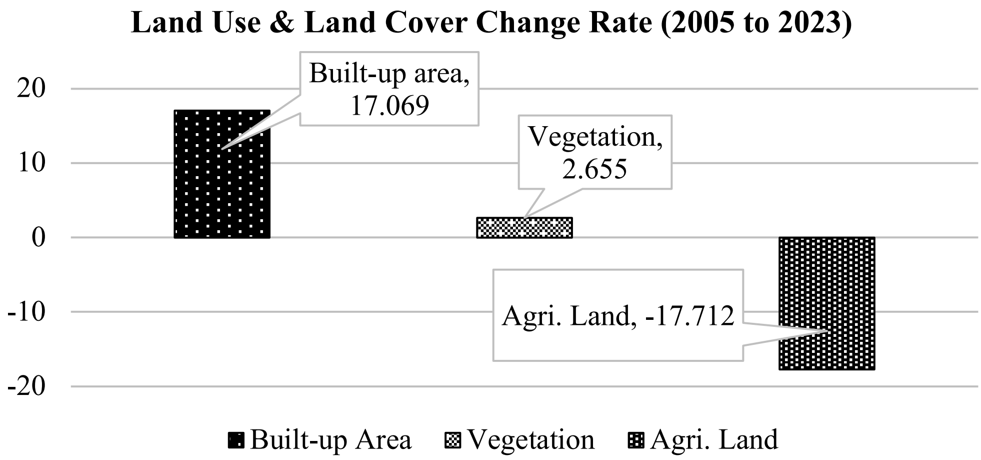


Figure 5: Land use and land cover change rate (2005 to 2023)

Table 2: Accuracy assessment table

Date	Kappa Hat Classification	Overall Accuracy
May, 2005	0.798	82.64%
Jun, 2015	0.913	92.63%
May, 2023	0.947	95. 67%

3.4 Discussion

3.4.1 Accuracy Assessment

Table 2 presents the accuracy assessment of classification results for May 2005, June 2015, and May 2023. It shows the Kappa Hat Classification values and Overall Accuracy percentages, which indicate improvements over time. The Kappa values were 0.798 in 2005, 0.913 in 2015, and 0.947 in 2023, and Overall Accuracy were 82.64 in 2005, 92.63 in 2015, and 95.67 in 2023.

3.4.2 Changes in Land Use Land Cover on St. Martin Island

The findings of the study underscore significant spatio-temporal changes on St. Martin Island from 2005 to 2023, validating the hypothesis that coastal tourism has profoundly impacted land use and land cover. The substantial increase in built-up areas, particularly in the northern regions, aligns with the surge in tourism activities and infrastructure development, as corroborated by prior research on the impacts of tourism on small islands. (Spalding et al., 2017b; Islam et al., 2016). These findings are consistent with the observed patterns of urban expansion and the decline of agricultural land documented by Ahmed et al. (2023), and Hossen and Sultana (2023).

The observed 17.73% increase in built-up areas and the corresponding 3.87% decrease in agricultural land clearly illustrate the island's transition towards urbanization driven by tourism. This trend echoes the patterns reported in similar changes (Ara et al., 2021). The rapid urban expansion not only alters the landscape but also poses threats to the island's ecological balance, particularly the fragile coral reef ecosystems. (Islam et al., 2016; Bhuyan et al., 2019).

The changes in agricultural land and vegetation cover on St. Martin Island reflect the complex dynamics between development and environmental management. From 2005 to 2015, vegetation cover experienced a 5.37% decline, likely due to expanding built-up areas and increased tourism activities. However, from 2015 to 2023, vegetation cover rebounded with an increase of 8.53%, resulting in an overall net growth of 3.17% during the study period. This recovery may be attributed to initiatives such as landscaping around tourist facilities or natural regrowth in less developed areas. Meanwhile, agricultural land saw a 4.43% increase from 2005 to 2015 followed by an 8.30% decrease from 2015 to 2023, leading to a net 3.87% decline over the period.

Similar trends have been observed in other coastal regions, such as those studied by Jiang et al. (2013) in China highlighted how urban expansion often leads to displacement of agricultural activities, while reforestation efforts can contribute to an increase in vegetation cover in response to environmental concerns. This dual trend on St. Martin Island indicates that while tourism infrastructure development has encroached on agricultural land, efforts to plant vegetation, particularly around tourist facilities, have led to some recovery in green cover.

The correlation analysis between the expansion of built-up areas and the reduction in agricultural land and initial vegetation cover decline indicates a direct impact of urbanization on these land cover types. This finding aligns with research by Wu et al. (2014), which demonstrated that urban expansion typically results in the loss of agricultural and natural lands. The subsequent increase in vegetation cover, as observed in this study, highlights the potential for mitigation through targeted reforestation and green space initiatives. These efforts are critical for maintaining ecological balance and can serve as a model for other regions facing similar development pressures.

Limitations of the study include inconsistent data on agricultural practices could lead to biased interpretations of their impacts. Additionally, natural events such as cyclones might not be fully accounted for, potentially skewing the results. Lastly, the study focuses on spatial and temporal changes without considering socio-economic factors, which could provide further insight into the driving forces behind the observed landscape changes.

However, the environmental implication of these land use changes is significant. The loss of agricultural land and fluctuations in vegetation cover can disrupt local ecosystems, reduce bio-diversity, and affect the livelihoods of communities' dependent on agriculture. Studies such as those by Špulerová et al. (2017) and Jackson et al (2007) have emphasized the importance of preserving agricultural landscapes and natural habitats to ensure sustainable development and ecological stability. The findings from St. Martin Island reinforce the need for integrated land use planning that balances tourism development with environmental conservation.

4. CONCLUSION AND RECOMMENDATIONS

This study helps to understand the landscape changes of St. Martin Island, the sole coral island of Bangladesh, through remote sensing and GIS analysis. Over the period of 2005 to 2023, our investigation unveiled a notable shift in land use and land cover, reflecting the island's evolving socio-economic and environmental dynamics.

Foremost among the observed trends was the rapid expansion of built-up areas, predominantly in the northern region, driven by the burgeoning coastal tourism industry. This transformation underscores the imperative for sustainable tourism planning and management to safeguard the island's ecological integrity amidst burgeoning urbanization pressures. Concomitantly, the decline in agricultural land signals a pivotal transition towards urbanization, necessitating concerted efforts to preserve agricultural spaces and underscore the delicate balance between development aspirations and environmental conservation.

The environmental ramifications of these changes are profound, with potential implications for habitat disruption and agricultural sustainability. Thus, proactive measures are warranted to mitigate adverse impacts and foster sustainable development pathways.

Based on these findings, several targeted recommendations have been identified. These involve promoting sustainable tourism, protecting agricultural landscapes, implementing vegetation conservation efforts, carefully managing infrastructure development, establishing strong data monitoring systems, and encouraging community participation in decision making.

By adopting these recommendations and embracing an integrated approach to land use management, policymakers, stakeholders, and local communities can collectively navigate the com-plex interplay between development aspirations and environmental preservation, ensuring a resilient and sustainable future for St. Martin Island.

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