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Spatio-Temporal Analysis of Vegetation Cover in Char Fasson and Galachipa Upazila of Bangladesh (1994-2024) Using Landsat Imagery

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Abstract

This research aims to analyse the spatio-temporal changes of vegetation cover in coastal regions of Char Fasson and Galachipa Upazila, Bangladesh for a period of 30 years (1994-2024) based on Landsat satellite imagery and NDVI. Through the evaluation of NDVI this paper classifies vegetation as no water/bare vegetation, slightly densed vegetation, moderately densed vegetation, and highly densed vegetation. The findings reveal significant fluctuations in vegetation cover: from 1994 to 2004, there has been an increase in vegetation density implying that afforestation has created more moderate and highly densed vegetation out of density vegetation. However, between 2004 and 2014, vegetation cover decreased because some cyclones, like Sidr and Aila, affected the coastal forest of Bangladesh. Other attempts to afforestation supported improved coverage from vegetation between 2014 and 2024. These findings provide clear evidence of the sustainable benefits of coastal afforestation in the reduction of coastal erosion and storm surges that affect vegetation and coasts. Knowledge gained in this research is highly useful to the environmental planners on recommendations for sustainable land uses and preservation to build up ecological stability in Bangladesh weak coastal areas.

Keywords

NDVI (Normalized Difference Vegetation Index), Remote Sensing in Vegetation Monitoring, Delta Cue Technique, Coastal Management, Cyclone Impact on Vegetation

1. Introduction

As most of the developing coastal states can attest to, low-lying coastlines are important in limiting global warming and acting as homes for numerous species and sources of income for over 20 percent of the world's population. The coastal regions of Bangladesh are critically important since they act as places that are both ecologically sensitive and economically very productive. However, these regions are also liable to natural and anthropogenic variations including those related to land use, deforestation, and climatic variations including sea-level rise, cyclones and coastal erosion. Coastal vegetation has a role of providing a cushion to the coasts against erosion, front line of control, support wildlife and bind agents to the soil. Follow-up to alterations in vegetation cover is crucial besides application in sustainable land management as well as in identifying how these shelves change following human interference and natural cycles. Over the years, afforestation strategies in our coastal zones have been adopted as measures for mitigating environmental degradation and climate change effects in the country. Some of these activities, especially in places such as Char Fasson and Galachipa have therefore been focusing on increasing vegetation capacities for protection of these coastal zones, and boosting their ecological resilience. But more important is the need to assess impact of these initiatives by observing the trends in vegetation cover year after year.

Bangladesh's costal vegetation maintains the ecological importance as well as socio-economic stability of the country's coastal belt. Bangladesh has about 710 km long coast line and coastal habitats are Mangroves, Saline Marsh and Different type of Seaweeds. These ecosystems include elements, like protection from storms and cyclones and subsidizing various marine species and flora, as well as resources for the local population [1]-[3]. Of these, the Sundarbans have a special importance because this largest mangrove forest in the world hosts such species as Sonneratia apetala, said to be the type used in plantation stock aimed at arresting the advancement of coastal erosion afforestation programs started in 1966 [1] [4] [5].

But the Bangladeshi coastal vegetation is now at risk of many anthropogenic and natural factors. Climate change impacts such as the changing sea level and salinity levels act as major threats to the existence of these ecosystems [1] [6] [7]. Research has highlighted that the physical and biological coastal vegetation structures are reduced by forces such as coastal erosion, flooding, and anthropogenic disturbances such as shrimp farming [7] [8]. The situation is made worse by the invasion of pests such as the Rugose spiraling whitefly that adversely affects the economically important plant species such as mangroves [9].

Coastal vegetation does not just serve as a source of livelihood for coastal population, but is very important to ecological systems. Coastal resources are used by many local populations for food, income and cultural practices [10] [11]. In addition, it is also virtual to state that coastal vegetation in shorelines bears the brunt of climate change related disasters applied as a buffer against storm surges and floods hence protecting human structures and property [2] [3].

The aim of this study is to assess and monitor the vegetation cover of Char Fasson and Galachipa Upazilas over a 30-year period, using Landsat satellite data from 1994 to 2024 and analyze trends in vegetation dynamics. The objective of the research is to identify vegetation coverage and the changes in the study area and determine the trend of vegetation coverage change since 1994.

The conclusion of this research will provide important data for environmental planners and policy makers to understand ways of managing coastal resources. The specific findings of the study can therefore assist in informing where vegetation cover has altered and can be useful in the formulation of more effective afforestation programs, land-use policies and other conservation initiatives in the coastal zones of Bangladesh. Different forms of vegetation especially along the coastal line play a crucial role in the mitigation of effects of storm surges, coastal erosion, and flooding. It is only when the densification pattern of vegetation over time is known, that the resilience of these areas to climate change can be determined. It can feed into national and regional action planning for adaptation to climate change. To reduce environmental crisis, Bangladesh has also established increased investment in the coastal afforestation. Including the evaluation of vegetation changes within the coastal ecosystems, the study contributes to current knowledge on these ecosystems with the help of long-term satellite data analysis. It will enhance the understanding of how coastal plant communities are affected by current and future environmental and anthropogenic stressors, hence can be used as a reference point for similar studies in other regions of the world in the future.

2. Methods

2.1. Study Site

Char Fasson Upazila is located between 21˚54'N to 22˚16'N latitude and 90˚34'E to 90˚50'E longitude (**Figure 1**). It is situated in the Bhola district of Bangladesh. Char Fasson Upazila is bordered by Lalmohan Upazila to the north, the Bay of Bengal to the south, Manpura Upazila, Shahbazpur Channel, and the Bay of Bengal to the east, and Dashmina and Galachipa Upazilas to the west.

Galachipa Upazila is located between 21˚48'N to 22˚21'N latitude and 90˚15'E to 90˚37'E longitude (**Figure 1**). It is situated in the Patuakhali district of Bangladesh. Galachipa Upazila is bordered by Patuakhali Sadar, Bauphal, and Dashmina Upazilas to the north, the Bay of Bengal and Rangabali Upazila to the south, Dashmina and Char Fasson Upazilas to the east, and Amtali and Kalapara Upazilas to the west.

2.2. Dataset

In this research, the Landsat Satellite Imageries are used which are secondary data. For the analysis of vegetation cover of 1994 and 2004, Landsat 5 images are used and for 2014 and 2024, Landsat 8 images are used which were gained from USGS website (https://earthexplorer.usgs.gov/). For Landsat 5 images, Band 3 and 4

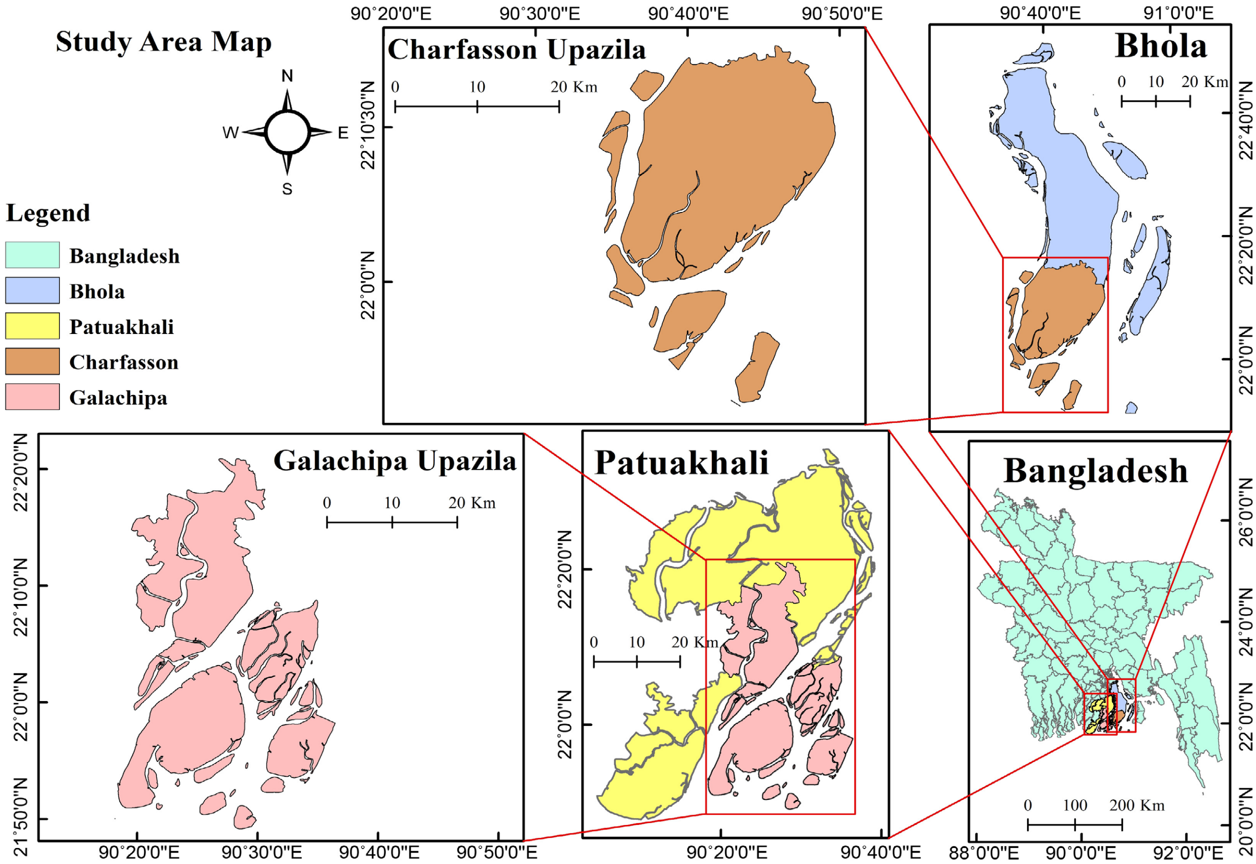

Figure 1. Study area map.

are used. For Landsat 8 images, Bands 4 and 5 are used. The Landsat Data Characteristics of the bands used Landsat 8 and 5 are highlighted in Table 1. For collecting the Landsat Images, the time period that was chosen was mainly the winter season. Because in the winter season, the cloud cover can be seen minimum compared to other seasons due to intense monsoon. Also, there can be seen clarified and stable vegetation characteristics in the winter season. And lastly, there is minimal agricultural activity in that time period which ensures that there minimized interference of cropping pattern to the vegetation cover.

Table 1. Landsat data characteristics.

Satellite	Sensor	Bands	Date of acquisition	Spatial resolution	Source
Landsat	TM 5	3 (Red), 4 (NIR)	18 January, 1994	30 m	USGS earth explorer
Landsat	TM 5	3 (Red), 4 (NIR)	15 February, 2004	30 m	USGS earth explorer
Landsat	OLI 8	4 (Red), 5 (NIR)	9 January, 2014	30 m	USGS earth explorer
Landsat	OLI 8	4 (Red), 5 (NIR)	5 January, 2024	30 m	USGS earth explorer

2.3. Methods

For this study, Landsat images for the years 1994, 2004, 2014, and an anticipated 2024 were obtained from the USGS Earth Explorer website using Landsat 5 for the earlier year and Landsat 8 for the later year but restricted to up to 10% cloud cover to enable accurate vegetation cover assessment. For the procedure, the downloaded images are of 30 m spatial resolution and in Level 1 Terrain-Corrected (L1TP) format. In ArcGIS, band composition creates multispectral composites to accomplish NDVI analysis which involved the use of the NIR and the red bands while, pan-sharpening improved the spatial resolution of land cover for better detail. NDVI, calculated using the formula in ArcGIS [12]:

$$\text{NDVI} = \frac{(\text{NIR} - \text{Red})}{(\text{NIR} + \text{Red})}$$

For Landsat 5, $\text{NDVI} = \frac{(\text{Band4} - \text{Band3})}{(\text{Band4} + \text{Band3})}$

For Landsat 8, $\text{NDVI} = \frac{(\text{Band5} - \text{Band4})}{(\text{Band5} + \text{Band4})}$

It gave information regarding the heath of the vegetation by providing highly densed vegetation and low density for the areas with slightly densed and bare vegetation. For NDVI, the value intensity is ranged from −1 to +1. For this research, the vegetation categories of the study area are distributed according to the following (**Table 2**) NDVI value intensity [13].

Table 2. Classification schema for vegetation cover.

Type of vegetation	NDVI value intensity
Water or No vegetation	(−)1 - (−)0.03
Slightly densed	(−)0.03 - 0.25
Moderately densed	0.26 - 0.35
Highly densed	0.36 - 1

Here, the parameters for waterbodies, to determine long term vegetation trends, the Delta Cue technique was used to subtract NDVI data from the two years and therefore identify positive values which implied vegetation gain and negative values which implied vegetation loss. For the analysis, version 10.8 of ArcGIS software was used. In the software, the Landsat Images of different time period were input and the required bands (Red and NIR) and the Bands have been processed by Delta Cue Technique by following the formula. In ArcGIS, Raster Calculator (Arc Toolbox → Spatial Analyst Tools → Map Algebra → Raster Calculator) tool was used to calculate the NDVI. In results analysis, graphical representations were employed including relevant line graphs to show temporal variation of vegetation cover. These were NDVI maps for the each of the study years, the vegetation cover maps and the graphic display of vegetation cover trends throughout the study period.

The Delta-Cue Technique is a strong technique applied in ArcGIS for analyzing the variations in vegetation cover at different period based on NDVI extracted from satellite data. It measures variations in vegetation health or density by taking the difference of the NDVI values at one time and that of another time. The equation for this technique is:

$$\Delta NDVI = NDVI_{Later} - NDVI_{Earlier}$$

Linear regression analysis was employed to identify trends in vegetation cover changes over the study period. The regression model used was represented by the equation,

$$y = mx + c$$

Here,

"y" = vegetation cover (area in square kilometers),

"x" = time (year),

"m" = slope of the line indicating the rate of change, and

"c" = y-intercept.

The vegetation cover was obtained from processed satellite images for the respective years, including 1994, 2004, 2014, and 2024. Separate data for each vegetation cover class (slightly dense, moderately dense, and highly dense) were considered. The area occupied by each vegetation class for the selected year was used as the dependent variable "y", while the variable "x" was the year.

The slope "m" was computed to express the change rate per year according to vegetation types. The vegetation indices "m" values were positive where there was an increase in the vegetation cover over the years and negative whereby there was a reduction in the vegetation cover. Therefore, based on the regression line the key issues related to vegetation changes and long-term trends in the coastal afforestation programs and other factors affecting vegetation growth were evaluated. The analysis was carried out using statistical program Microsoft Excel as it offers the values of regression coefficients and the graphical outputs illustrating trends. All the research procedures are visually shown in Figure 2.

3. Results

This study indicates temporal changes in the vegetation density of Char Fasson and Galachipa Upazila from 1994 to 2024 (**Table 3**). The results indicated a slight regression of the slightly dense vegetation by 763.37 sq·km between 1994 and 2004 while the moderately dense vegetation gained a corresponding area of 1001.65 sq·km and the highly dense vegetation also gained 59.36 sq·km (**Table 4**). These changes suggest a shift from a low to a higher vegetation density, likely due to afforestation and coastal development activities at this time (**Figure 3**).

On the other hand, from 2004 to 2014 the region saw loss of denser vegetation cover coinciding with cyclone Sidr (2007) and Aila (2009). Slightly dense

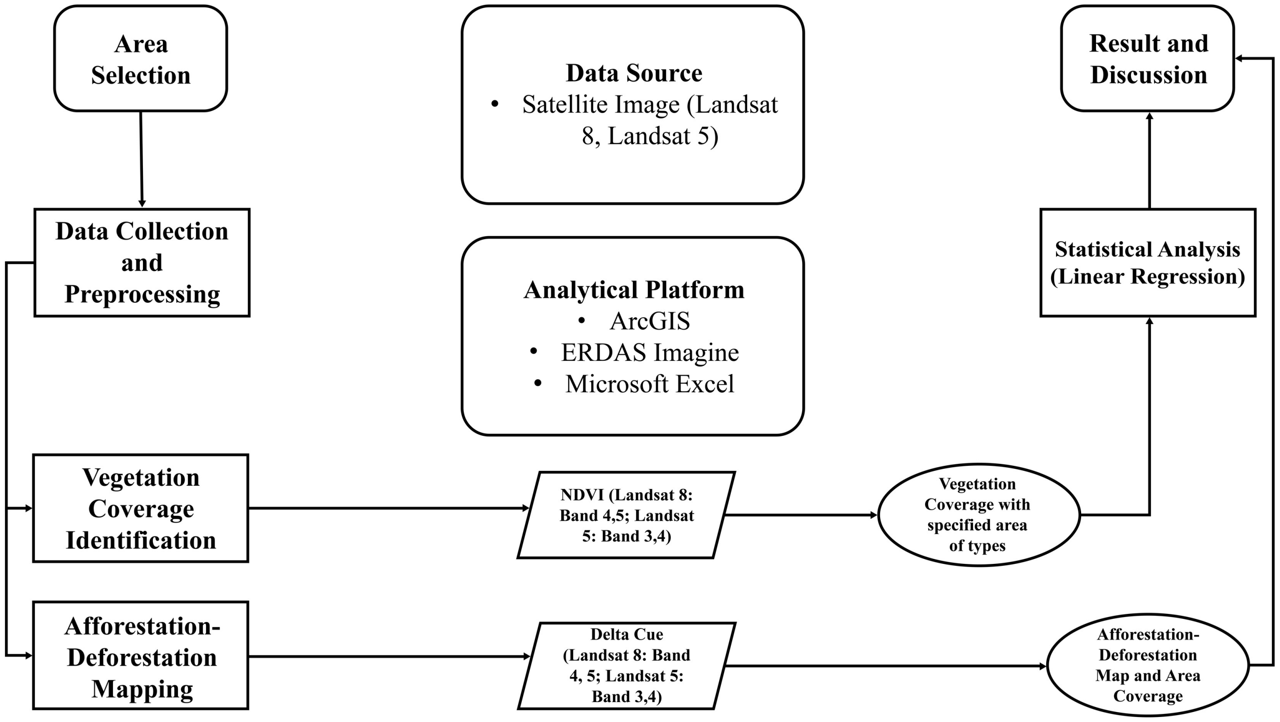

Figure 2. Flowchart of methodology.

Table 3. Total area (sq·km) of vegetation cover types (1994-2024).

Type of vegetation cover	1994 Area (sq·km)	2004 Area (sq·km)	2014 Area (sq·km)	2024 Area (sq·km)
Slightly densed	1032.82	269.45	789.13	1028.99
Moderately densed	7.52	1009.17	551.36	379.97
Highly densed	0	59.36	0.36	0.87

Table 4. Total area (sq·km) of change of vegetation cover types (1994-2024).

Type of vegetation cover	1994-2004 area change (sq·km)	2004-2014 area change (sq·km)	2014-2024 area change (sq·km)	1994-2024 area change (sq·km)
Slightly densed	(−) 763.37	(+) 519.68	(+) 239.86	(−) 3.83
Moderately densed	(+) 1001.65	(−) 457.81	(−) 171.39	(+) 372.45
Highly densed	(+) 59.36	(−) 59.0	(+) 0.51	(+) 0.87

vegetation was the only type that gained an area of 519.68 sq·km, moderately dense vegetation lost an area of 457.81 sq·km while highly dense vegetation lost 59.0 sq·km (Table 4). This period further reveals that there is arising risk of potential destruction of coastal vegetation due to storms.

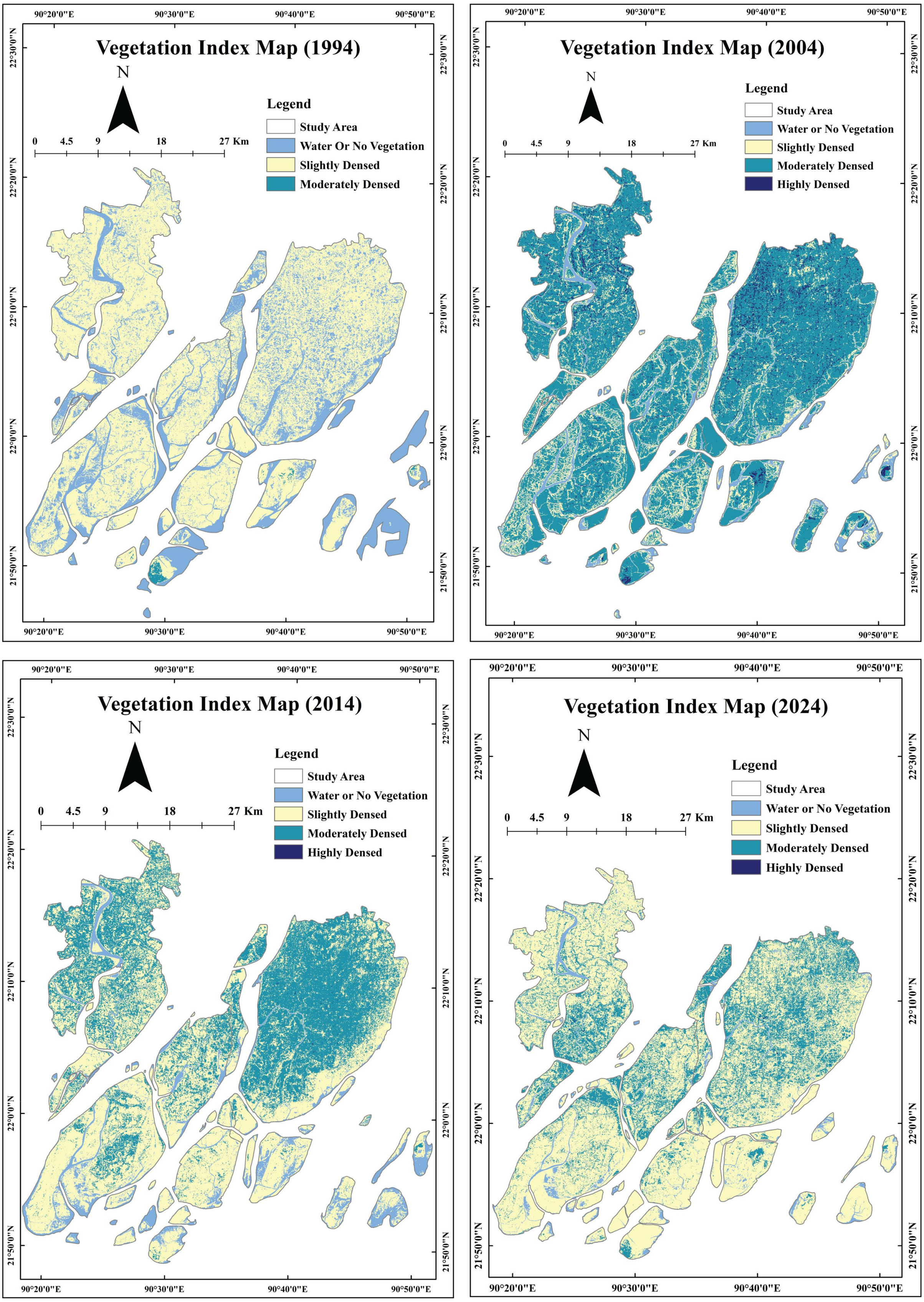

Figure 3. Vegetation index map of 1994, 2004, 2014 and 2024.

In detail, from 2014 to 2024 slightly dense vegetation area slightly increased by 239.86 sq·km, while moderately dense vegetation area slightly reduced by 171.39 and highly dense vegetation area slightly expanded only by 0.51; thereby, from 1994 to 2024 slightly dense vegetation area slightly decreased by 3.83 sq·km, moderately dense vegetation area increased by 372.45 sq·km (**Table 4**).

The temporal dynamics of the vegetation cover in the study area for the 30-year (1994-2024) show positive and negative changes (**Figure 4**). Positive changes in vegetation area between 1994 and 2004 were observed in 316.93 sq·km of vegetation, while negative changes were observed in 22.96 sq·km of vegetation (**Table 5**). This gives a picture of a net gain in vegetation cover, especially as result of enhancements in the afforestation exercises.

In the following period of 2004 to 2014, the trend was again reversed with positive changes decreasing to 47.46 sq·km while the negative changes rose steeply to 56.76 sq·km (**Table 5**). This period may be said to have registered a net decrease in vegetation cover possibly due to anthropogenic pressure coupled with low rate of afforestation.

As for the period of 2014-2024, the areal dynamics of the positive change augmented up to 84.82 sq·km and negative change declining to 19.84 sq·km (**Table 5**).

Thus, the net inclination of vegetation cover during 1994-2024 was positive 352.03 sq·km, but the negative classes were 14.61 sq·km (**Table 5**). All these trends depict the continuous interaction between afforestation programs and people's activities in determining vegetation cover transformation.

Table 5. Total area (sq·km) of vegetation cover change from postive to negative (1994-2024).

Type of change	1994-2004 area change (sq·km)	2004-2014 area change (sq·km)	2014-2024 area change (sq·km)	1994-2024 area change (sq·km)
Positive change	316.93	47.46	84.82	352.03
Negative change	22.96	56.76	19.84	14.61

The satatistical analysis uses linear regression analysis to assess spatial dynamics of vegetation cover for the period between 1994 and 2024 based on different density classes of vegetation cover as explained below.

In the case of slightly densed vegetation the current study found the rates are little down trend for the period of 30 years which has been declined by 3.83 sq·km. This means that the modest improvement evident during 2004 to 2024 failed to cancel out the decline evident from 1994 to 2004. The number of areas with a moderately dense vegetation cover gradually rises, up by 372.45 sq·km in total. This implies enhanced afforestation activities or increase in vegetation cover

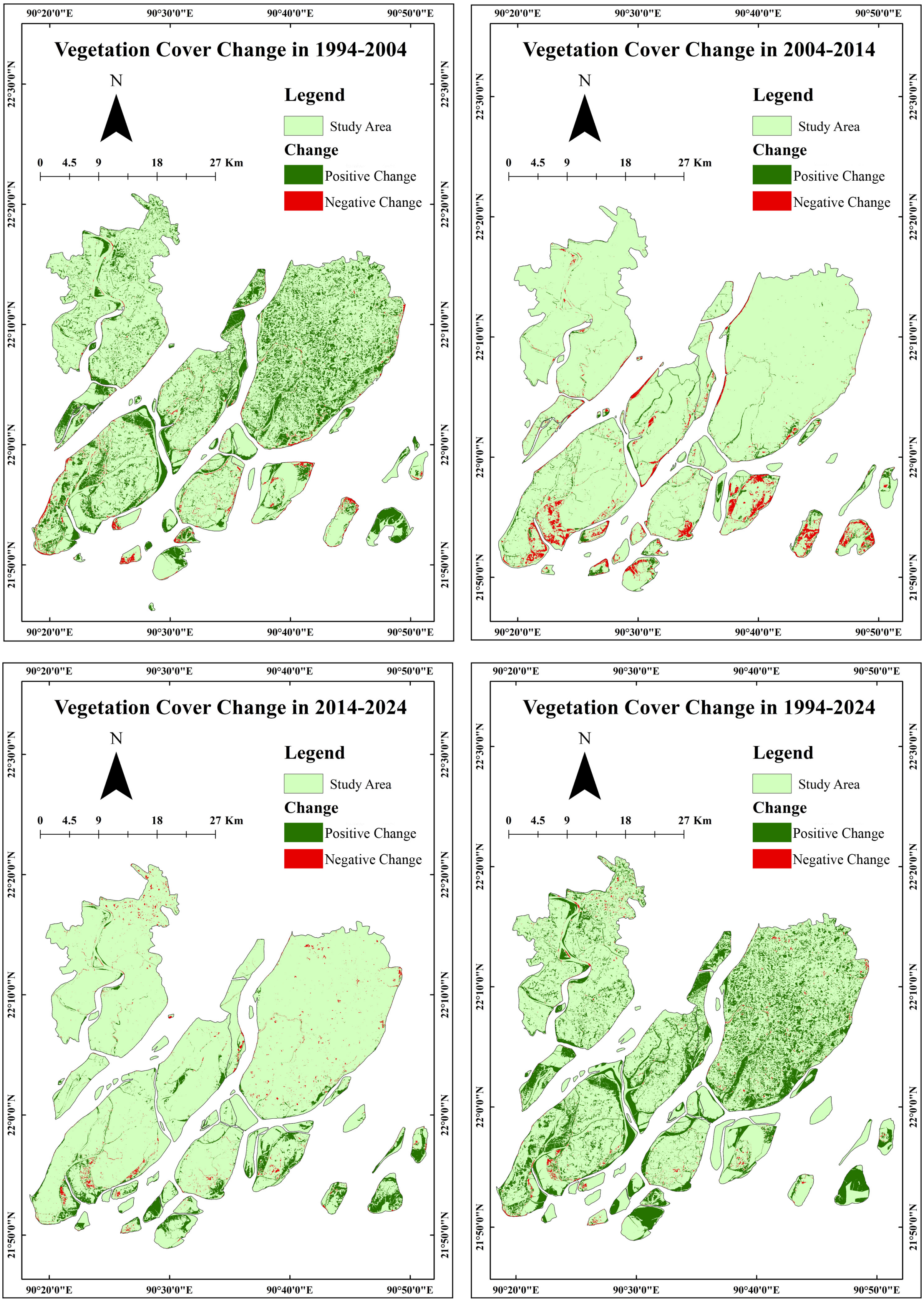

Figure 4. Vegetation cover change in 1994-2004, 2004-2014, 2014-2024 and 1994-2024.

density in these regions during the period 1994-2004.

Highly densed vegetation shows modest enhancement of only 0.872 sq·km over 30 years, and overhead imaginary transmits exactly this information. Despite this positive transition, the rate of increase is shallow when compared with other classes, suggesting limited expansion of core dense vegetation zones.

As for the trendlines emerging from the regression analysis, it will be seen that whilst moderately dense vegetation has undergone a pronounced enhancement, slightly and highly dense categories have been changing only minimally in general (Figure 5). This systematic study brings out the changes in vegetation cover density over time as measures the afforestation activities and land use changes in the study area.

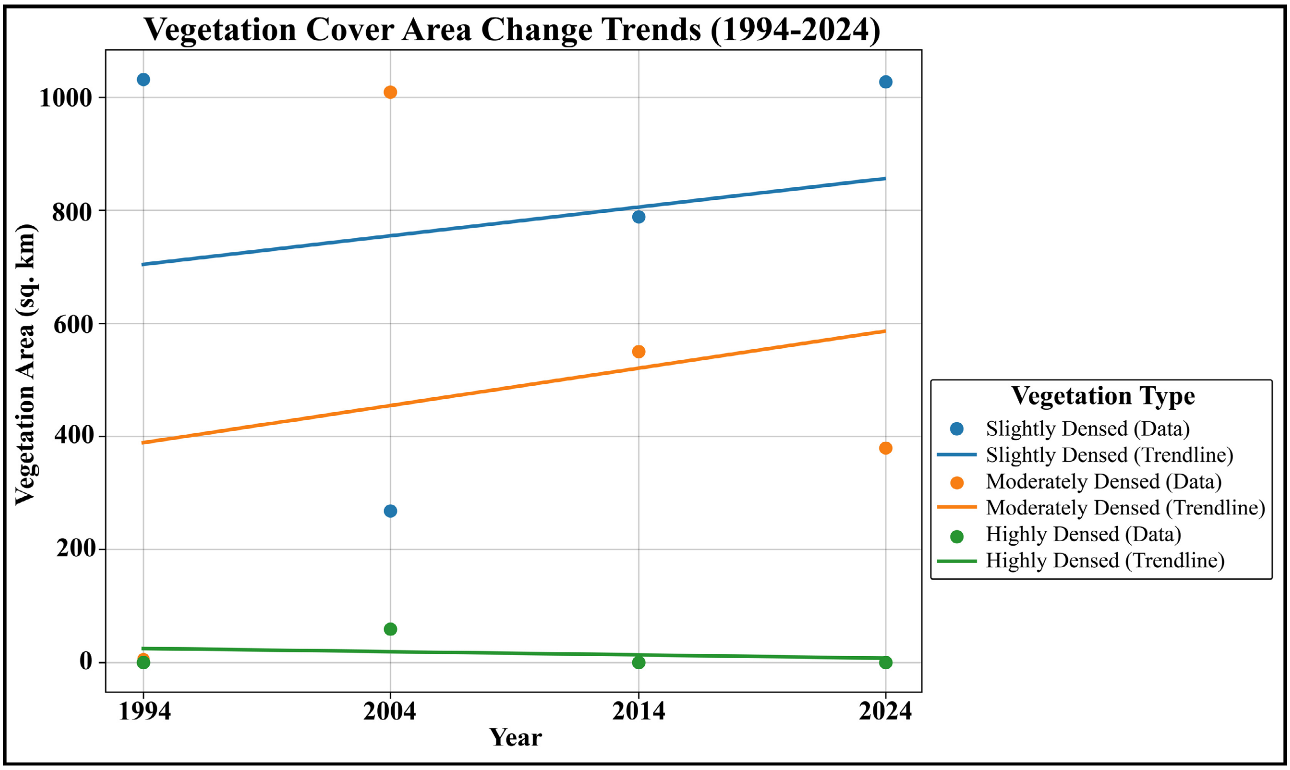

Figure 5. Vegetation cover area change trends (1994-2024).

4. Discussion

In the vegetation cover of the study area, there are three types of vegetation cover, which are slightly, moderately, and highly densed vegetation. From 1994 to 2004, the slightly densed vegetation cover has decreased by 763.37 sq·km, which is quite a large portion. On the other hand, the moderately densed vegetation cover has gained an increment of 1001.65 sq·km., and the highly densed vegetation cover has gained an increment of 59.36 sq·km. This shows that in that period of time, the vegetation cover has increased from 1994 to 2004, and a large number of slightly densed vegetation has been converted into moderately densed vegetation, and moderately densed vegetation has turned into highly densed vegetation cover.

From 2004 to 2014, the slightly densed vegetation had increased, which has an area of 519.68 sq·km. On the other hand, the moderately densed vegetation had gained a decrease of 457.81 sq·km, and the highly densed vegetation had a decrease of 59.0 sq·km. In this period of time there some cyclone such as Cy-clone Sidr in 2007, Cyclone Aila in 2009 and so on negatively impacted the Bangladesh coastal region and greatly damaged the coastal belt by leaving the area with a small percentage of the vegetation cover actually. Because of this, the vegetation cover of the area can be seen in decline, which has affected that area in that period of time. From 2014 to 2024, the slightly and highly densed vegetation have an increment of 239.86 sq·km. and 0.51 sq·km., respectively, and the moderately densed vegetation cover has decreased by 171.39 sq·km.

In this period of time, the moderately densed vegetation cover got converted into slightly densed vegetation a lot and the highly densed vegetation in a little portion. The slightly vegetation cover in this period of time was also increased by natural and human-effort activities. As a whole, from 1994 to 2024, the slightly densed vegetation decreased by 3.38 sq·km in total, and the moderately and highly densed vegetation increased by 372.45 sq·km and 0.87 sq·km, respectively. From 2004 to 2014, the decrease can be seen very significantly, as there were some tropical cyclones that happened in that period, which affected the whole vegetation cover and the Bangladesh Forest Department (BFD) in that period of time after the cyclones overtook afforestation activities to protect the coastal belt.

It is the findings of this research that show important findings in change in vegetation cover in the study area for the period 1994 to 2024, both gains and losses. It is seen from the above analysis that during the period 1994 to 2004, vegetation cover gained rather than lost, a net gain of 316.93 sq·km vegetation covers as against a loss of 22.96 sq·km. From this, afforestation or natural regeneration, probably, due to the decade of coastal conservation, was presumably carried out. Nevertheless, the scenario observed between 2004 and 2014 portrayed a different picture whereby vegetation loss recorded was 56.76 sq·km while vegetation gained was only 47.46 considering fears of environmental degradation or high land-use pressures. The last decade between 2014 to 2024 revealed further improvement marked by 84.82 sq·km of positive shift and only 19.84 sq·km of negative shift that can be ascribed to recent afforestation programmes.

Linear regression blends that were conducted showed similar patterns of development with regards to vegetation density. Analysis of overall trend with fluctuations of slightly dense vegetation showed declining while that of moderately dense vegetation reflected an increasing trend over the study period. High density vegetation changed little and though there were a slight addition between 2014 and 2024. These relationships were traced by the regression trendlines ($y = mx + c$) with positive value of m for moderately and highly dense vegetation and almost zero value for slightly denser vegetation.

An integrated assessment as it depicts the dynamic interactions between restoration and degrading forces in the environment of the region. The expanding areas have a connection to coastal afforestation projects, and the shrinking areas are prone to anthropogenic pressure and climate change impacts. The arithmetic of the Delta-Cue technique and the regression analysis testing enabled quite credible evaluation of trends and the dynamics of change. The result of this work supports continuation of afforestation and conservation efforts to enhance ecological resilience in the study area. Subsequent researches should investigate socio-economic factors and perform field validation to gain general understanding.

5. Conclusions

This research aimed at identifying change patterns in vegetation cover of Char Fasson and Galachipa Upazila over the last thirty years using Landsat images. With NDVI, it was also possible to evaluate the changes in vegetation production that took place in the sampled areas during 1994-2024 period.

The provided results show clear shifts in producer biomass that can be associated with both internal and anthropogenic processes. From 1994 to 2004, there was a substantial increase in vegetation cover, especially the conversion of slightly densed vegetation to moderately and highly densed vegetation. The rise in this aspect can be explained by the reforestation programs that the Bangladesh Forest Department (BFD) has implemented around the coastlines in order to assert the region from erosion additional from cyclones. The trend moved from 2004 to 2014, in which there observed a reduction in vegetation density, primarily because of cyclones such as Sidr in 2007 and Aila in 2009 that greatly affected their coastal vegetation. Nonetheless, the BFD countered this with afforestation measures, and once again, afforestation coverage trended up between 2014 and 2024. Hence, the overall trend of vegetation from 1994 to 2024 shows that there was some positive increase in vegetation cover thus showing that the afforestation programmes have been fruitful in replacing the lost vegetation cover though disasters have periodically reversed the gains.

The findings of this research emphasize the importance of continued afforestation efforts and sustainable land management to ensure the resilience of coastal ecosystems in Bangladesh. Long-term monitoring of vegetation is essential to adapt to the impacts of climate change and natural disasters, ensuring the sustained protection and growth of the region's natural resources.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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