ASSESSING FOREST HEALTH OF THE SUNDARBAN MANGROVE THROUGH ADVANCED GEOSPATIAL AND REMOTE SENSING TECHNIQUES

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ABSTRACT

The Sundarbans, the world's largest mangrove forest and a UNESCO World Heritage Site, is an important hotspot for biodiversity, a natural barrier against cyclones and coastal erosion, and a carbon sequestrator. This special ecosystem is under immense threat for various reasons, like sea level rising, climate change, and increasing different anthropogenic activities. The health of the forest must be monitored accurately in order to facilitate efficient conservation and management. This study focuses on assessing and monitoring the health of the Sundarbans mangrove forest using advanced geospatial techniques and remote sensing data in the cloud computing platform named Google Earth Engine (GEE). To assess the forest health of Sundarban, different parameters related to forest environment, such as Canopy Cover (CC), Canopy Height (CH), Forest Persistence (FP), Above Ground Biomass (AGB), Below Ground Biomass (BGB), Leaf Area Index (LAI), Gross Primary Productivity (GPP), and Normalized Difference Vegetation Index (NDVI), were estimated from different secondary datasets applying remote sensing techniques. The results indicate some powerful insights to monitor the forest health. The total area of Sundarban in the Bangladesh part in 2020 was 3893.79 km², where only 5.01 km² area has FP greater than 0.90 and 29.44 km² area has a value greater than 0.80. The total AGB carbon of Sundarban is 14446852.37 Mg C. And the total BGB carbon of Sundarban is 3970848.5884 Mg C. The mean CH of the Sundarban was found to be 7.04 m, the maximum CH of the Sundarban was found to be 26.00 m, and the 99th percentile of canopy height was found to be 16.99 m. The eastern part of the Sundarban was seen as more productive than the western part. The average GPP for the years 2021-24 was found to be 1.77, 1.92, 1.73, and 1.71 kg C/m²/year. The higher LAI value was found on the eastern side. The maximum value of LAI was 3.18, and the mean value was 2.61.The NDVI timeseries from 2000 to 2025 was analyzed, and it was observed that the maximum value of NDVI was shown in Oct-Dec and the minimum NDVI was shown in Jul-Aug. To preserve the undisturbed ecosystem services of the Sundarbans, the results highlight the critical need for conservation efforts, sustainable resource management, and well-informed policy choices. This study demonstrates how remote sensing technologies can be used to improve adaptive and timely management plans to strengthen the conservation efforts.

Keywords: *Sundarban, Forest Health, Canopy Cover, Biomass, Forest Persistence.*

1. INTRODUCTION

Mangrove forests are recognized worldwide for their enormous productivity and significant provision of ecosystem services, and they act as a buffer between the terrestrial and coastal environments. The Sundarbans, situated on the mouth of the outfall of the GBM delta between Bangladesh and India, is the world's largest natural mangrove forest and a UNESCO world heritage site having tremendous significant universal value. This mangrove not only provides coastal protection against cyclones and storm surges but also acts as a carbon sequestrator. It also helps by cycling nutrients and supporting rich biodiversity and fisheries. Mangrove forests are an essential and unique environment because of its enormous ecological, hydrological, economic, and social significance. (Spalding et al, 2021). Additionally, mangroves are crucial for land reclamation, safeguarding the coastal ecosystem from tidal surges and storms, cyclone and improving the socioeconomic standing of coastal populations. (Das, S.C. et al, 2022). For this, it is very urgent to monitor the health in an efficient way.

Various variable related to the forest health can be monitored by modern advanced remote sensing techniques, since the global scale data is readily available in different renowned platform now a days. Some prominent forest health variable can reflect the condition of the health of the forest. The "mean" height of the tallest tree stratum in a stand should be represented by the forest's canopy height. (Taro Nakai et al, 2010). Where there are no obvious signs of human activity, and ecological processes are not seriously disrupted, those parts of the forest can be defined as the persistent forest. Thus, forest persistence can be considered one of these types of parameters. (Forest Data Partnership, 2024). Biomass is the measure of the total carbon captured by the forest. Gross primary productivity is the measure of the total photosynthesis of the forest. Leaf area index is the ratio of leaf area of one side to ground area. NDVI, a very popular vegetation index, widely acceptable for the monitoring the forest health.
Remote sensing provides the opportunity for monitoring forest health, which is cost- and time-efficient, and also enables continuous monitoring for a large area. Combining this technique with a cloud platform makes it easier to apprehend and grasp a deeper idea about the forest health.

The current study tries to assess the forest health by using satellite data available through advanced cloud computing platform by geospatial and remote sensing techniques. The main focus is to determine spatial and temporal quantification of vegetation health indicative variable such as canopy height, forest persistence, above -ground and below-ground biomass, leaf area index, gross primary productivity, normalized difference vegetation index, spatiotemporal area changes of Sundarbans.

2. METHODOLOGY

2.1 The Study Area

Sundarban, in Bangladesh, is situated in the Khula, Bagherhat, and Satkhira districts. It is surrounded by the Bay of Bengal in the south, Pirojpur and Barguna in the east, the plainland of Khula, Bagherhaat, and Satkhira in the north, and the Indian Sundarban in the west. The geographic extent is from latitude 22.501792 N to 21.654874 N and longitude 89.03487 E to 89.875 E. The total area of Sundarban according to the Bangladesh government is about 601,700 hectares, which is 4.13% of the country's area and 38.12% of the forest land controlled by the Forest Department. The main river flowing through the forest are Pashur, Shivsha, Baleshwar and Raymangal. It is a world heritage declared by UNESCO in 1997.

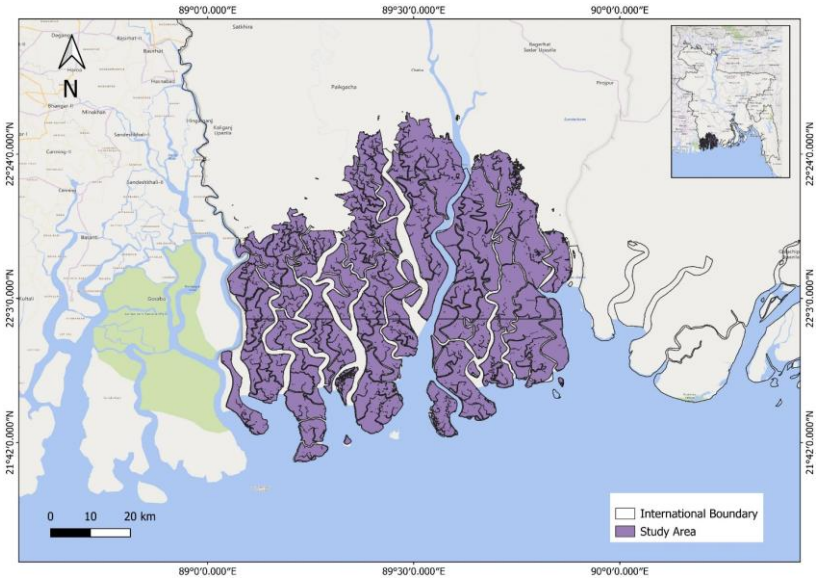

Figure 1: The study area of Sundarban in Bangladesh.

2.2 Methodology for CH

The region of interest, represented as a GeoJSON file from the asset section, was loaded into the GEE code editor, and the CH dataset was also loaded and combined into a single image. A forest mask was created by applying a threshold greater than 0 to extract forested areas. A histogram of height distributions was prepared for statistical analysis, and key parameters were calculated. The CH height data were classified into three distinct categories to prepare a CH map. (Tolan, J., 2024)

2.3 Methodology for FP

The necessary datasets for forest persistence and the boundaries of Bangladesh and the Sundarbans were loaded into the GEE code editor. Forest persistence data was clipped with the boundaries of Bangladesh and Sundarban for analysis. Ten persistence levels were created from 10 percent to 95 percent persistence by thresholding. The binary mask was separated according to the persistence, and areas were calculated. (Forest Data Partnership. 2024)

2.4 Methodology for Biomass

The secondary datasets from NASA's carbon density information and ROI of Sundarban were loaded in the GEE code editor. The biomass data was clipped to the ROI, and aboveground and belowground carbon density was estimated from the clipped ROI. Total AGB and BGB carbon was calculated by multiplying respective bands with pixel areas and employing sum reducer over the ROI. (Spawn, S. A. et al, 2020)

2.5 Methodology for GPP

The boundary of Sundarban was initialized in the cloud platform, and the MODIS Gross Primary Productivity dataset was loaded. The GPP of the desired ROI was extracted by the required spatiotemporal filter. A 0.0001 multiplier was used to scale the raw GPP data into actual units of kg

C/sqm/yr. Statistical analysis was done to determine the mean and standard deviation. (Running, S., & Zhao, M. 2021)

2.6 Methodology for LAI

Loading the Sundarban regional boundaries and calling the datasets from JAXA's GCOM-C Leaf Area Index were done in GEE. Daytime observations for required spatiotemporal data were extracted by filtering. The raw data was scaled with the proper scaling factor to get the actual LAI value and unit. Histograms and other statistical parameters were calculated from the reduced region of the ROI. (Kobayashi, T. et al, June. 2020).

2.7 Methodology for NDVI

The process was initiated by declaring the ROI boundaries of Sundarban and calling the MODIS NDVI dataset and filtering it for the required time period. Time periods were divided into four parts so that they comply with the memory limit of GEE for a single run. The timeseries was plotted in the console with necessary annotation. (Didan, K., 2021).

2.8 Methodology for Spatiotemporal Change Analysis

The area changes over time were analyzed from the secondary area data collected from Global Mangrove Watch. Then all the vector files were imported to the cloud computing platform of GEE. The area was calculated from the imported files and was stored in a dictionary to print in the console. A timeseries chart was generated from the area data, and the minimum, maximum, and mean areas were also calculated. (Bunting, P. et al, 2022)

3. RESULTS AND DISCUSSION

3.1 Canopy Height

The mean canopy height of the Sundarban was found 7.04 m, maximum canopy height of the Sundarban was found 26.00 m, the 99th percentile of canopy height was found 16.99 m. The figure shows the distribution of three class of canopy coverage throughout the Sundarban. From left class 01 shows canopy height map of less than 5 m, class two shows canopy height map of between 5 to 10 m and class here shows canopy height map of greater than 10 m.

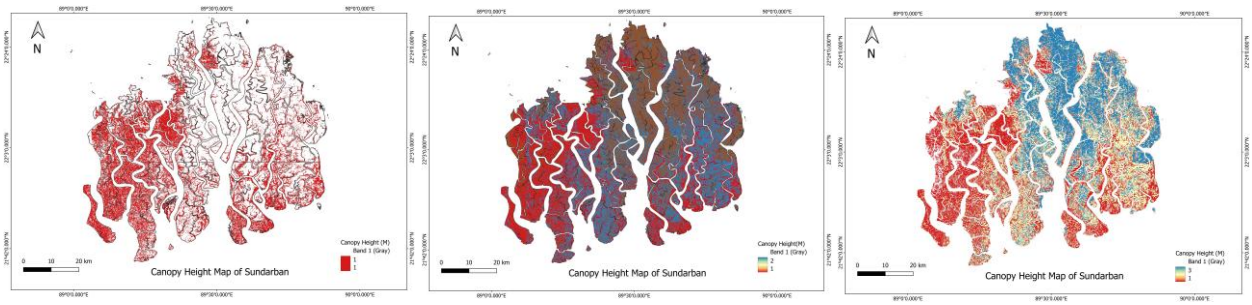

Figure 2: Canopy Height Map of Sundarban in Bangladesh.

Figure 3 represents the histogram of canopy height vs pixel frequency. Frequency in the vertical axis and canopy height in horizontal axis. It illustrates the canopy height occurrence frequency of tree cover of Sundarban.

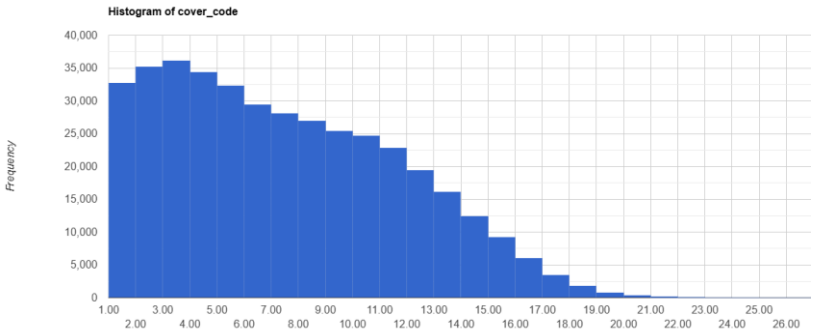

Figure 3: Histogram (Canopy Height vs Pixel Frequency).

3.2 Forest Persistence

The term "forest persistence" refers to forests that are "predominantly composed of trees established through natural regeneration" or that naturally regenerate and show "no clearly visible indications of human activities and the ecological processes are not significantly disturbed." The numerical support, known as Forest Persistence, is generated using an ensemble of pre-existing datasets selected for their ability to represent forest disturbance and management history in compliance with the requirements. It has a value between 0 and 1. The data has a spatial resolution of 30 meters. Only 5.01 km2 area of Sundarban having Forest Persistence value greater than 0.90, 29.44 km2 area has value greater than 0.80.

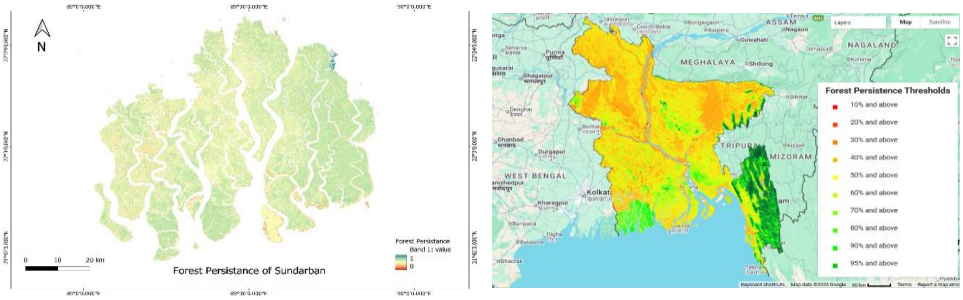

Figure 4: Forest Persistence Map of Sundarban in Comparison

3.3 Biomass

The carbon stored in living plant tissues found above the surface of the earth (stems, bark, branches, and twigs) is included in the aboveground living biomass carbon (AGB) stock density of combined woody and herbaceous cover. Leaf litter and coarse woody debris that were formerly linked to living plants but have subsequently been deposited and are no longer living are not included in this. The carbon stored in living plant tissues found beneath the earth's surface (roots) is included in the belowground living biomass (BGB) carbon stock density of combined woody and herbaceous cover. This excludes both soil organic materials and dead or displaced root tissue. Sundarban's total

aboveground biomass carbon content is 14446852.37 Mg C. Sundarban's total belowground biomass carbon content is 3970848.5884 Mg C.

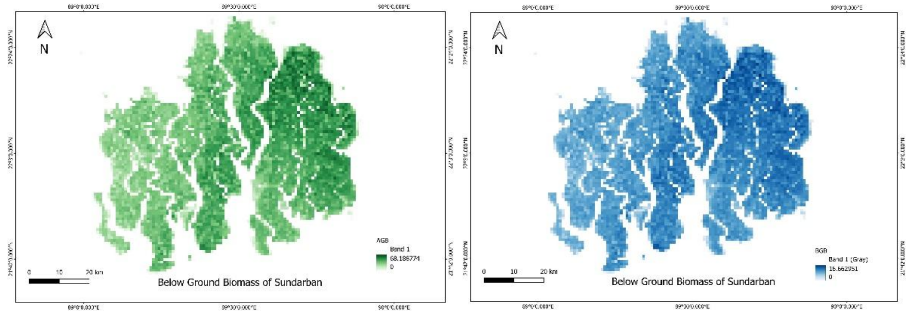

Figure 5: The AGB and BGB Carbon map of Sundarban in

3.4 Gross Primary Productivity (GPP)

The average GPP for the years 2021-24 was found to be 1.77, 1.92, 1.73, and 1.71 kg C/m²/year. The figure 6 shows the mean GPP of 2024 of Sundarban in Bangladesh. It shows that the GPP value of the east part is higher than the west part of the forest.

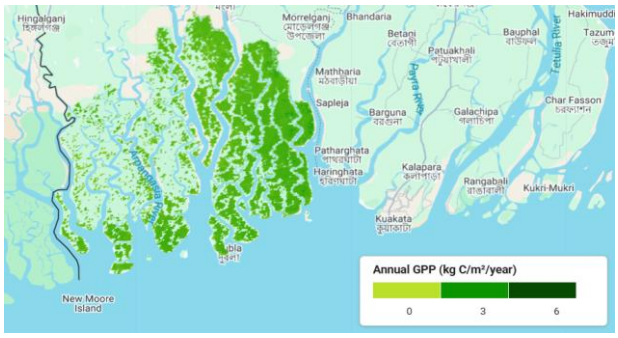

Figure 6: The mean GPP of 2024 of Sundarban.

3.5 Leaf Area Index (LAI)

The higher LAI value was found on the eastern side. The maximum value of LAI was 3.18, and the mean value was 2.61.

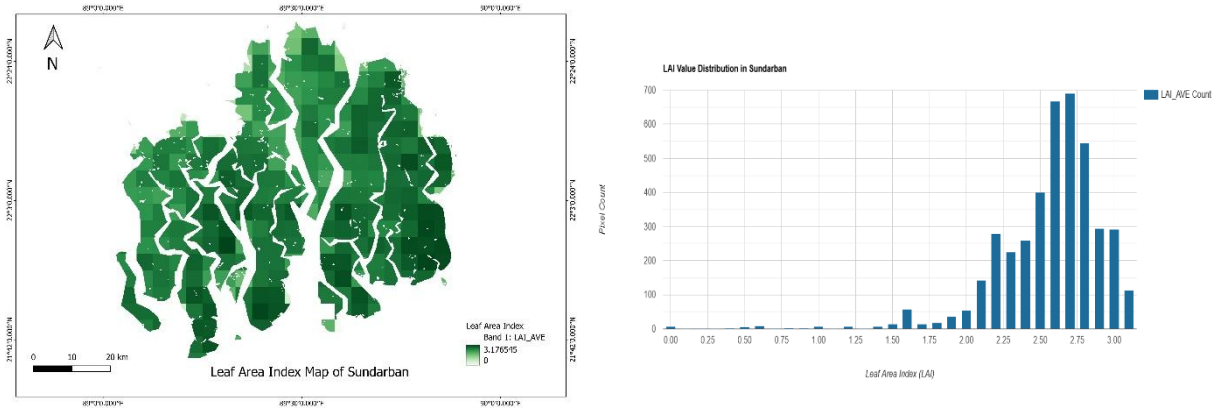

Figure 7: The Leaf Area Index Map with Histogram of Sundarban.

3.6 Normalized Difference Vegetation Index (NDVI)

NDVI is a popularly used vegetation index to assess the health of vegetative land. The value of the NDVI ranges from the -1 to +1, higher the value of the NDVI, healthier the vegetation. the maximum

value of NDVI was shown in Oct-Dec and the minimum NDVI was shown in Jul-Aug. This periodicity was observed all through the years.

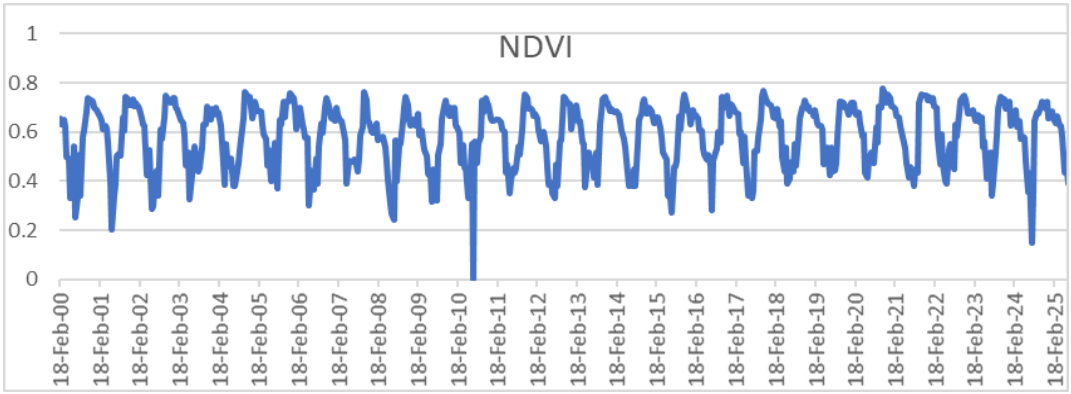

Figure 8: NDVI time series from 2020 to 2025.

3.7 Spatiotemporal Change Analysis

From the calculation, the area of Sundarban in 1996 was found to be 3941.10 sq km; in 2007 it was 3959.08 sq km; in 2008 it was 3957.62 sq km; in 2009 it was 3956.08 sq km; in 2010 it was 3946.46 sq km; in 2015 it was 3916.92 sq km; in 2016 it was 3905.78 sq km; in 2017 it was 3904.53 sq km; in 2018 it was 3905.42 sq km; in 2019 it was 3901.12 sq km; and in 2020 it was 3893.793 sq km. The overall trend of area change is decreasing.

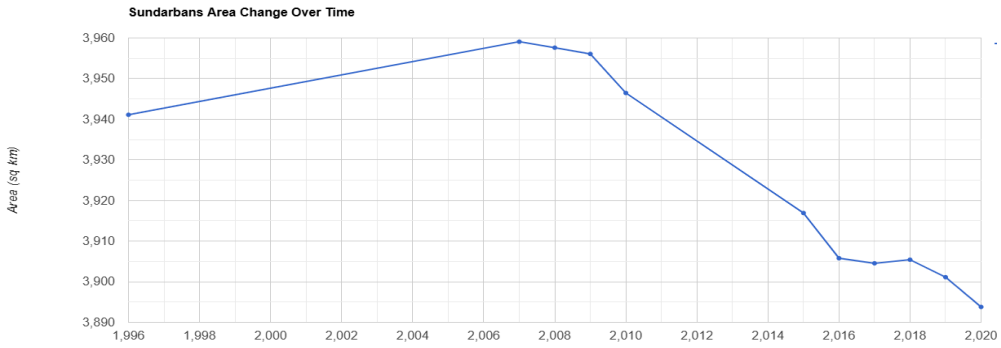

Figure 9: Sundarban's Area Change over Time from 1996 to 2020.

4. CONCLUSIONS

Assessing forest health is very important and has a significant impact on the environment monitoring and decision making in national and international level. To sustain the ecological services that has been provided from the mangrove of this delta, the observation and assessment of mangrove health is very much necessary. The seven parameters that has been observed can be a critical tool to assess the health of the mangrove forest. It provides the readily available method to have an idea about the change and associated health at any time. The method can be extended to measure the before and after condition of the mangrove immediately after a disaster, which will be a great instrument for a practical measurement of the forest condition. This study also laid a way to advanced application of the cloud platform and remote sensing data in case of forest health monitoring. The short term and long-term reflection of the forest health indication was also be measured in these techniques.

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