Sundarbans Mangrove Mapping and Above Ground Biomass Estimation Using Earth Observation Techniques

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Abstract: The Sundarbans, the world's largest mangrove forest, plays a crucial role in Bangladesh's economy and environment. However, overexploitation, anthropogenic activities like tree cutting for development and agriculture, as well as natural disasters, have caused severe damage and changes to the Sundarbans. This research aims to detect changes in the mangrove forest areas and create an above-ground biomass map of the Sundarbans Forest. Previous studies relied on time-consuming and inaccurate traditional methods, while this study seeks to make a significant contribution to mangrove mapping and forest resource management. Landsat 5 and 8 images from 2007 to 2017 were used to generate the mangrove index (including CMRI and MI) for different years. ALOS-PALSAR 2 and JERS images from 1996, 2007, and 2017, with HV+HH polarization, were processed to calculate the backscatter ratio, enabling identification and estimation of vegetation loss and gain over the years. To estimate the above-ground biomass (AGB), tree height was derived from SRTM DEM, and an allometric equation was used to calculate AGB. The results indicate a continuous shrinkage of the mangrove forest. The 2017 maps of the two different indexes reveal significant mangrove vegetation loss compared to 1996 and 2007. Additionally, the study estimates the total above-ground biomass of the Sundarbans mangrove forest to be 329 million tons. The findings can assist relevant authorities in taking necessary action, formulating policies, and implementing plans for sustainable management of the Sundarbans mangrove forest resources.

Keywords: *Biomass, Deforestation, Forest management, Mangrove mapping, Remote sensing*

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1. Introduction

The mangrove forest is composed of woody vegetation communities that grow along the coastal area, typically in tropical and subtropical latitudes, in regions where saline water exists, such as the land-sea interface, bays, and estuaries (Qasim, 1998). Organisms in this environment have specifically adapted to survive (Spalding, 2010). Both natural causes and anthropogenic activities contribute to mangrove forest degradation. Natural events like cyclones, tsunamis, and storm surges can impact mangrove areas and ecosystems, while climate change-induced sea-level rise poses a significant threat to mangroves (Alongi, 2008). Additionally, anthropogenic activities such as clear-cutting, land-use change, hydrological alterations, and chemical spills, including oil spills, pose significant risks to mangrove forests (Gilman et al., 2008). Furthermore, mangrove conversion for agriculture, aquaculture, urban development, and tourism infrastructure also contributes to the decline of mangrove forests. Numerous studies indicate that if the current destruction continues, mangrove forests could disappear globally within 100 years.

Despite their resource-providing capabilities and role in coastal protection, mangrove forests face immense pressure and are experiencing destruction and decline. Sundarbans, the world's largest single-block mangrove forest, spans approximately 10,000 sq. kilometers between India and Bangladesh, with around 6,000 sq. kilometers located within Bangladesh (Getzner & Islam, 2013). Due to natural causes and anthropogenic activities, the Sundarbans is shrinking continuously, with a 1.2% decrease in forest area between 1973 and 2000 (Giri et al., 2007). Human-induced actions such as deforestation for aquaculture, agriculture, infrastructure, urban development, and tourism contribute to this degradation (Rahman, 2010). It is essential to map the extent of the mangrove forest, identify deforestation areas, and determine locations for afforestation to regenerate degraded forests. Additionally, estimating forest resources such as above-ground biomass can assist in decision-making for conservation, sustainable use, and protection of mangrove forests.

While mangrove forest estimation poses challenges, remote sensing plays a crucial role in efficiently, accurately, objectively, rapidly, and inexpensively monitoring mangrove changes over large areas and different years. Forest inventory and ecological surveys are commonly used to map and estimate forest resources like biomass and carbon stock by collecting data on forest extent, tree species, age, and annual increment. However, collecting biophysical parameters for biomass estimation through field inventories is tedious, time-consuming, costly, and challenging to apply in large and heterogeneous forests (Englhart et al., 2012). Additionally, regular interval data is necessary for forest management, further complicating the process.

Currently, there is a lack of accurate, objective, rapid, and inexpensive mapping techniques to monitor mangrove changes over large areas and different years. To address this gap, efficient, purposeful, rapid, and inexpensive mapping techniques are required. Remote sensing already plays an essential role in mapping mangrove forest extent, vegetation loss, vegetation gain, and resource estimation (Islam et al., 2019). Various methods and techniques have been applied to map and estimate mangrove forests. The United Nations Environment Programme (UNEP) made the first attempt to estimate the global mangrove area with the Tropical Forest Resources Assessment project in 1980, estimating 156,426 km2 of mangrove area across 51 countries (Alexandris et al., 2014). Another study utilized high-resolution optical images, specifically Landsat TM satellite data and image processing techniques, which offer benefits over conventional photo-interpretative mapping techniques. However, the accuracy of remote sensing mapping is influenced by the classification procedure, and optical data can be affected by weather conditions (Long & Skewes, 1996). Several studies have focused on observing the status of mangrove forests using remote sensing approaches, including the India-Bangladesh Sundarbans region (Giri & Long, 2014). Previous studies mostly covered the combined India-Bangladesh Sundarbans area, with only a few concentrating on the Bangladesh portion. Some studies have attempted biomass estimation using parameters like Diameter at Breast Height (DBH) and Tree Height in the Allometric Equation (Siddique et al., 2012). However, these parameters are often retrieved through time-consuming and costly field inventory approaches. Therefore, this study's novel approach of utilizing Earth observation techniques, specifically SAR data (JERS and ALOS-PALSAR 2), to map the extent of the Sundarbans mangrove forest and estimate above-ground biomass and carbon stock makes a significant contribution to the field. This approach overcomes limitations of previous methods, such as weather effects and the time and cost associated with field inventory methods.

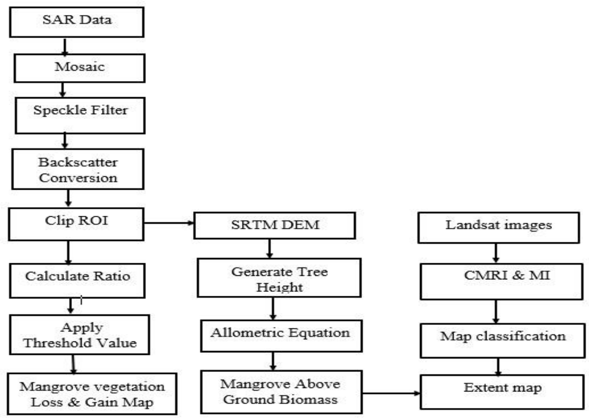

Figure 1: Methodological framework

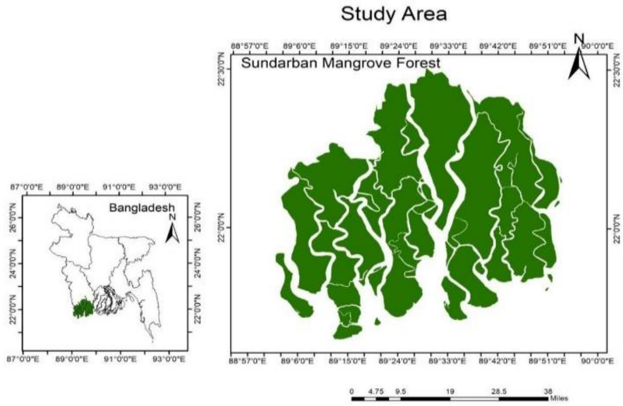

Figure 2: Map of Sundarbans

2. Materials and methods

The Sundarbans Forest is one of the largest mangrove forests in the world, located in the delta region of the Padma, Meghna, and Brahmaputra rivers. It spans across the Khulna, Satkhira, and Bagerhat districts of Bangladesh, as well as parts of India, covering a total area of approximately 10,000 square kilometers (UNESCO, n.d.). Among global mangrove forests, it is the largest continuous block of tidal halophytic mangrove forest, situated in the southern part of Bangladesh (between latitudes 21˚30‟N and 22˚30‟N, and longitudes 89˚00‟E and 89˚55‟E) (Sundarbans, The - Banglapedia, n.d.). The original size of the Sundarbans was approximately 16,700 square kilometers, but it has now shrunk to about one-third of its original size. After the partition of India, Bangladesh received about two-thirds of the forest, while the remaining portion is located in India. In the Bangladeshi portion, the estimated area is around 6,000 square kilometers, with 4,300 square kilometers being land area and the remaining 1,700 square kilometers occupied by water bodies (Sundarbans, The - Banglapedia, n.d.). The Sundarbans occupies a significant portion of the total vegetation in Bangladesh and is rich in natural resources such as Sundari, Gewa, Goran, and Keora trees (Iftekhar & Saenger, 2008). It plays a vital role in the weather, environment, and moisture regulation in the region (Neogi et al., 2017). The

Sundarbans is also a valuable repository of natural resources, including biomass and carbon. Unfortunately, it faces the pressures of deforestation and damage from both natural events and human activities and development. For instance, in 2007, around 40% of its vegetation was damaged by Cyclone Sidr (Khan, 2016). Therefore, accurate mangrove mapping, deforestation monitoring, and above-ground biomass (AGB) estimation are crucial for the conservation and sustainable use of the Sundarbans mangrove forest.

For this research, ALOS PALSAR 2, JERS images were collected from JAXA's website. Landsat-8, 5 were also used to generate mangrove index E.g., CRMI & MV. For image processing and analysis, Google Earth Engine, ArcGIS 10.5 and SNAP (software) were used. Other product such as SPSS, Excel were also be used for data analysis.

Table 1: Characteristics of different images

Name	Satellite	Sensing Date
N22E089_96_MOS.tar	JERS-1	1996
N22E089_07_sl_HV	Alos-PALSAR2	2007
N23E089_17_sl_HV	Alos-PALSAR2	2017
LC08_L1TP_138045_20171108_20200902_02_T1.tar	Landsat 8	2017
LT05_L1TP_137045_19961022_20200911_02_T1	Landsat 5	1996
LT05_L1TP_137045_20070223_20200830_02_T1.tar	Landsat 5	2007

Mangrove extend mapping

To determine the extent of Sundarbans mangrove forest two indexes (CMRI &MI) were generated using Landsat data. For generating Combine Mangrove Ratio Index (CMRI) Normal Difference Vegetation Index (NDVI) and Normal Difference Weight Index (NDWI) were determined using following equations.

NDWI is generated for mangrove vegetation as mangroves exhibit a property of high-water content in its leaves, which is to an extent exploited using this index. Whereas, NDVI uses the greenness of leaves and its absorption and reflection of Red and NIR band to extract information based on the plant chlorophyll content. In order to generate an index to distinguish mangroves from other vegetation types using both the above-mentioned indices sensitive to mangroves (Gupta et al., 2018).

NDVI= (NIR-RED)/(NIR+RED)

NDWI=(NIR-SWIR)/(NIR+SWIR)

After this, NDWI values are subtracted from NVDI value to generate CMRI.

CMRI=NDVI-NDWI

Finally, a suitable threshold value was used to produce mangrove extent. Due to unique nearshore habitat of mangrove forest, MRI can respond sensitively its spectral signals and bigger the MRI of a pixel more likely that it belongs to mangrove forest. While MRIs of other ground covers, such as terrestrial vegetation, water, bare soil, etc. are less than that of mangrove forest (Zhang Xuehang, 2013) and that's why this index is used in this study.

Mangrove Index (MI) was generated using the following equation.

MI=(NIR-SWIR)/(NIR×SWIR) ×10000

Using the two indexes, the extent of Sundarban Mangrove Forest was determined.

Mangrove vegetation gain and loss mapping

The extent of Sundarbans Mangrove Vegetation gain and loss from 1996-2017 and 2007-2017 are identified using both JERS and ALOS-Palsar1 and 2 images. As single image does not cover the full study area, multiple images were used. But running same processes for different segment is time consuming and also inefficient. By mosaicking of images, this can be avoided. Mosaicking Image is the process of combining two or more image data in an image. For this study, JERS 1996 And ALOS-PALSAR-2 of 2007 and 2017 were mosaicked to cover the full Sundarbans in a single image. Due to the interference of waves reflected from many elementary scatters, speckle appearing in Synthetic aperture radar (SAR) images as granular noise. It complicates the image interpretation problem in SAR image by reducing the effectiveness of image segmentation and classification (Lee et al., 1994) so "Speckle Filtering" is applied. There are several types of filters. The choice of filter depends on work purpose. Adaptive filters like Frost and Lee try to suppress Speckle based on local (adaptive) statistics. DN value of image converted into backscatter value. There are different equations for different sensors for the conversion. For ALOS FALSAR, the following equation (Shimada et al., 2009) was used.

$NRCS = 10\, log_{1o}\, DN2$

Where NRCS= normalized radar cross section

DN= digital number

Further image Clipping is important to create a study area or specific area of interest. It can discard the unnecessary spatial information with no loss to core data. It also increases the quality and save processing time. By calculating the ratio of present and previous image, extend and change with in the image can be identified. In this study ALOS-PALSAR 2007, 2017 and JERS 1996 were used to generate the ratio map to identify the extent of change (gain, loss) of the forest. Eventually mangrove maps for different time period with forest gain and loss were determined and statistic such mean, standard deviation for forest gain, loss and no change also were produced. From the statistic, threshold value for each aspect were generated and apply to classify the mangrove forest to see the change of forest.

Above ground biomass estimation

For estimating Above Ground Biomass of Sundarbans mangrove forest using Allometric equation, tree height is used. Tree Height is generated using SRTM DEM. Mangrove Forest grow in the flat land along the coast, DEM elevation in the mangrove area is free from topological effect hence the elevation in the DEM represents the height of tree accurately. After generating tree height from DEM, Above Ground Biomass for mangrove forest is estimated using follow Allometric equation.

$AGB = 3.25 * 〖1.08SRTM〗^{1.53}$

Using this equation, a single tree's biomass can be measured. To estimate Biomass for single pixel, this single tree biomass has multiplied with pixel size. The image that is used in this study has 25m *25 m pixel area.

Pixel wise AGB= AGB* 25*25

By adding all the pixel AGB, total biomass is calculated for the Sundarbans.

Total AGB= Sum of all pixel wise AGB size.

3. Results and discussion

3.1. Mangrove extend mapping

To map the extent of Sundarbans mangrove forest, two indexes (CMRI & MI) are generated using Landsat-8, Landsat-5 data set for year 1996, 2007 and 2017.

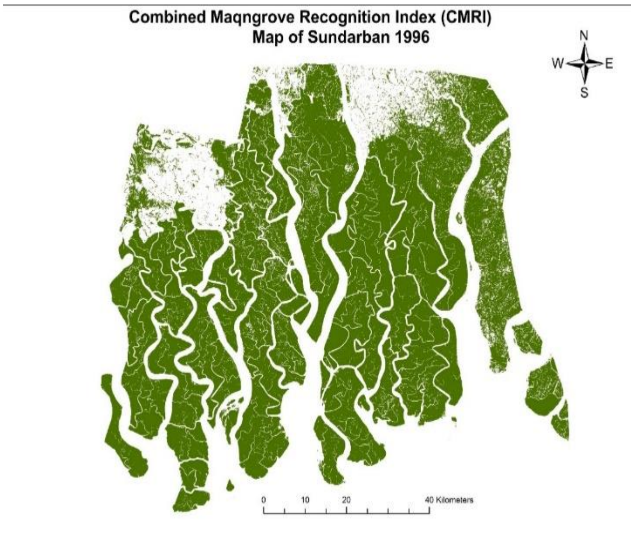

Figure 3: Mangrove extent map 1996

Map 1996 show that there is dense mangrove vegetation within Sundarbans forest and some mangrove vegetation are also shown in the nearest outside of the forest (mainly in the south outside part).

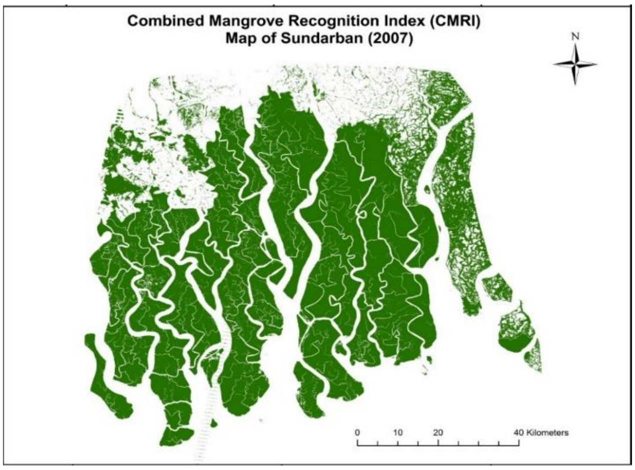

Figure 4: Mangrove extent map 2007

Map 2007 show that there are some changes (reduction) of mangrove vegetation within the forest but a great amount of mangrove vegetation is lost from the adjacent area of Sundarbans, mainly in the north-east side of forest.

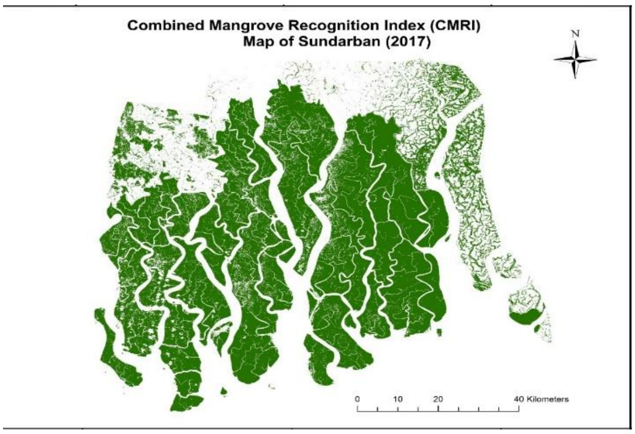

Figure 5: Mangrove extent map 2017

In 2017, map show that there is greater change in vegetation within the Sundarbans and its outskirt. Mangrove vegetation along with rivers within forest area and east out-side of the forest are greatly destroyed.

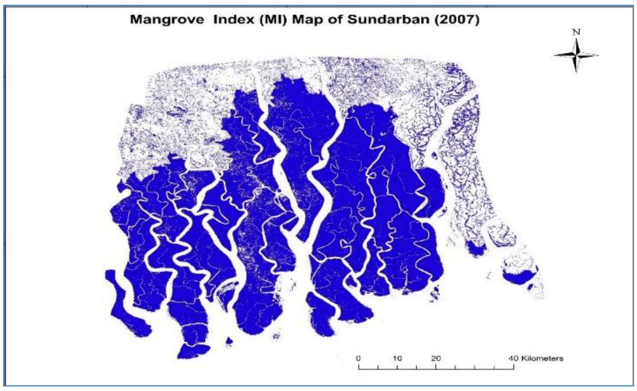

Figure 6: Mangrove extent map 2007

Generating Sundarbans mangrove forest extent map using different (Mangrove Index), we can see that in 2007 there are some changes in the extent of mangrove vegetation as mangrove plant are deforested and loosed mostly in the outer side of forest.

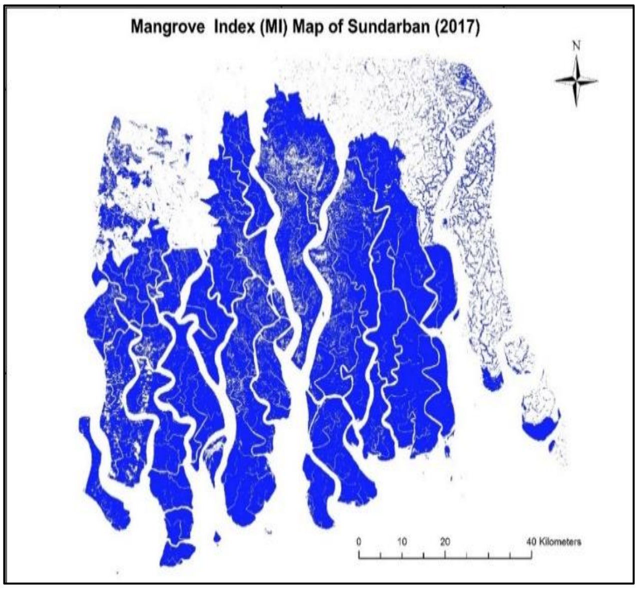

Figure 7: Mangrove extent map 2017

Mangrove Index (MI) of 2017 shows that there is a great change in the extent of mangrove vegetation. Most of the vegetation losses are occurred outside of the forest and within the forest there are some extents of vegetation loss which took place mainly along the coast and riverside.

In this study, the extent of Sundarbans mangrove forest is generated using two different mangrove indexes (CMRI & MI). Two indexes are used because comparing the result of these two indexes for the same time period, extent can be determined more accurately. In 2017 maps of these indexes show a great amount of mangrove vegetation loss compare to the 1996 and 2007. In 2007 and 2017 maps of CMRI & MI show almost same extent of Sundarbans with some loss of mangrove vegetation within and outer side of the forest from the analysis, it is evident that the Sundarbans forest is shrinking fast as mindless grabbing and tree felling continue which is threating to the existence of this natural treasure and pushing its flora and fauna towards extinction.

3.2. Mangrove vegetation gain and loss map

Using SAR data such as JERS and Alos-Palsar image for different time scale, forest vegetation loss & gain maps are generated which is showed using different color in the maps.

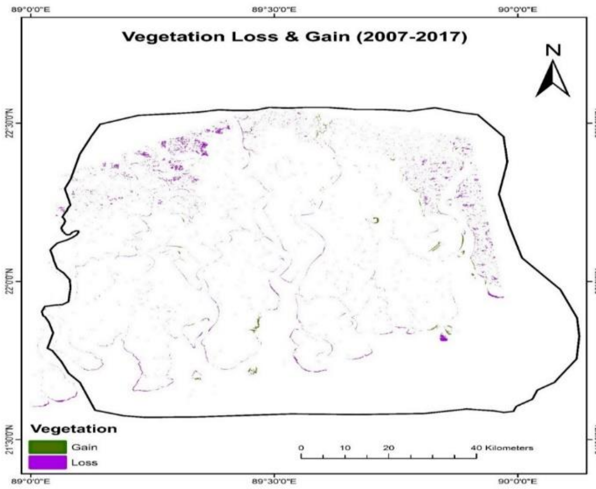

Figure 8: Forest vegetation loss & gain map 2007-2017

To identify and estimate the change of Sundarbans mangrove vegetation for different time period, forest vegetation loss and gain maps are produced. The loss and gain maps of 2007-2017 shows that there are certain amount of vegetation loss and occurred within and adjacent area of Sundarbans Forest. Most of the gains and losses are happened along the coast of sea, river and island area of Sundarbans mangrove forest.

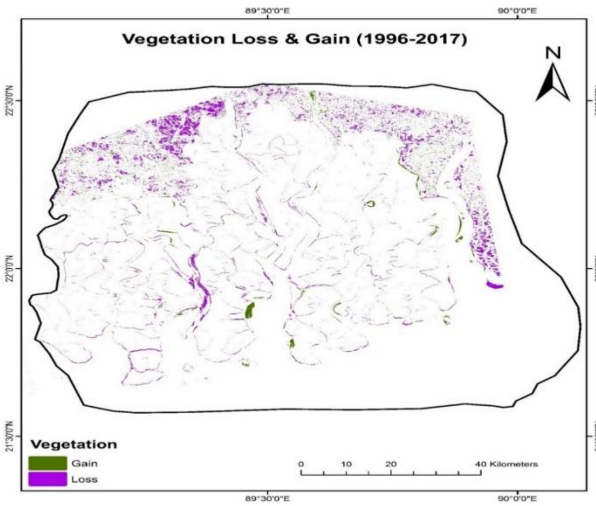

Figure 9: Forest vegetation loss & gain map 1996-2017

In 1996-2017 map, it can be seen that a large amount of vegetation losses is occurred compared to the year from 1996-2017. Most of the loss happened in the east adjacent area of Sundarbans Forest and long the rivers bank within and outside of the forest. Forest vegetation gain is small in amount compared to the losses that took place from the year 1996-2017.

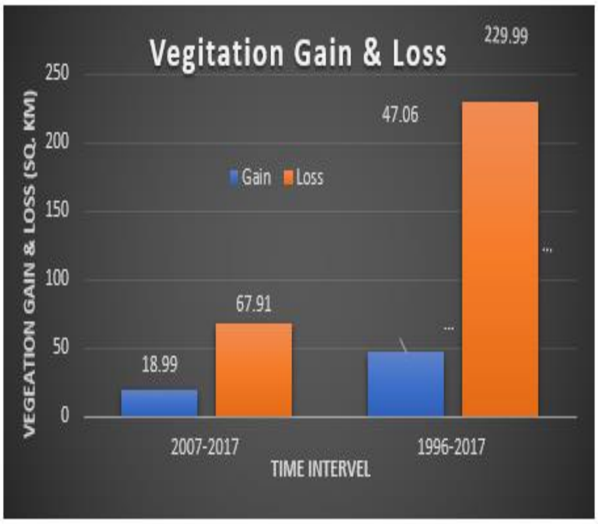

Figure 10: Vegetation loss & gain diagram

From the chart, it can be seen that in ten years (2007-2017) the vegetation gain is 18.99 square km. where loss is occurred 67.91 square km which is more than three times of vegetation gain. And in last 21 years (1996-2017) Sundarbans has gained only 47.06 square km. of vegetation and lost 229.99 square km. of vegetation.

The extend map and vegetation gain and loss map of different time period indicate that the mangrove area is shrinking day by day as well as the mangrove vegetation is also subjected to deforestation in the Sundarbans and adjacent area. From the field work, I talk to different people of that area to identify the dominant causes of this regard. According to them and my observation the major causes of vegetation loss are poverty and greed of the people, they cut down tree and sell it for livelihood and profit-making. Poor forest management is another major cause of forest lost which is intensified with natural disaster like cyclone SIDR, increased salinity and sedimentation in this area. Different developmental construction like embankment and unplanned tourist spots is also a factor of mangrove vegetation loss. The vegetation gains also took place in small amount. People and local government plant tree along the sides of embankment and the coast area. Government have taken different project and activities to regenerate lost area and plant new area for the protection of local people from different natural hazard.

3.3. Above ground biomass

Above ground biomass of Sundarbans mangrove forest are estimated for the year 2017 using ALOS-PALSAR image and digital elevation model. For this estimation tree height is used in Allometric equation. Tree heights are generated from SRTM DEM. As mangrove are grown along the coast side which usually flat in nature and subject to tide regularly, the height of mangrove in DEM represents the actual height of the tree and it's free from topological effects.

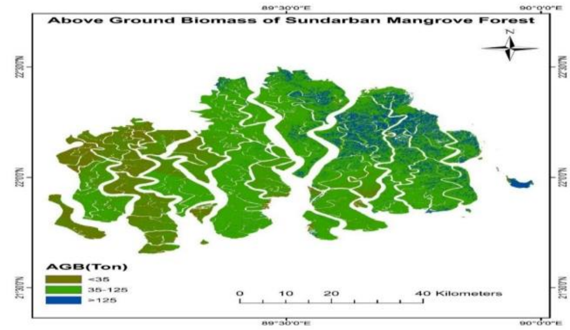

Figure 11: AGB map of Sundarbans mangrove forest

In this map there are three classes of above ground biomass based on the pixel value of biomass which is shown using different color in the map. AGB<35 tons are grouped in class 1, AGB between 35-125 tons are grouped in class 2 and lastly AGB>125 are grouped in class 3. From field observation, it was found that the density and height of the tree of class three are higher than other two classes. From the map, it can be seen that major portion of Sundarbans biomass belong to class 2, some portion only show higher biomass value.

Three heights were generated from SRTM DEM and using this height in Allometric equation (AGB= 3.25*(1.08*SRTM) ^1.53), biomass for single tree height was estimated. Then this biomass was multiplied by the pixel size of image to generate pixel wise Above Ground Biomass. By adding all the pixel value of biomass of the study area, total biomass of the Sundarbans is estimated. From the estimation, it is found that the Above Ground Biomass (AGB) of Sundarbans mangrove forest is 329 million ton.

4. Conclusion

This study has successfully generated an extent map and estimated the vegetation gain and loss, as well as the above-ground biomass, of the Sundarbans mangrove forest. The results clearly indicate a rapid and alarming rate of mangrove shrinkage, with vegetation declining at a much faster rate than it is regenerating. The primary drivers of this concerning trend are human activities, including deforestation for agriculture and fuel, unplanned development, poor forest governance, and natural disasters. The study highlights the urgent need for decision-making, policy formulation, and planning aimed at conserving and sustainably utilizing the vegetation resources to protect the Sundarbans mangrove forest.

The proposed method of continuous monitoring, utilizing satellite datasets and secondary data, offers an accurate and cost-effective approach for monitoring mangrove extent, deforestation, and above-ground biomass. This method is crucial for the protection and sustainable management of this vital ecosystem. The findings of this study can serve as a valuable resource for policymakers, government officials, and other stakeholders, enabling them to take necessary actions in preserving and safeguarding the Sundarbans mangrove forest.

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