"Development of maps for delineation of project boundaries, developing sampling design and collection of data on pools of carbon, Sundarban Tiger Reserve"

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...towards global sustainable development

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Introduction

Tiger reserves provide a safe shelter for tigers and other wildlife species, along with providing a host of ecosystem services. In Sundarban Tiger Reserve, forest occupies about 60% of the total area of the Tiger Reserve, with very dense and moderately dense Mangrove forests and Open forests. Mangroves and Mangrove associates constitute the dominant vegetation type of the area. The mangrove flora includes halophytic plants with modifications to survive the waterlogged saline soils, like, *Excoecaria sp., Rhizophora* sp., *Xylocarpus sp*. etc. Numerous villages along the northern and western boundaries of the tiger reserve rely on the forests for crab collection, fishing, honey collection and collection of wood for fuel. In the project area, unsustainable resource extraction and siltation constitute a significant cause of forest degradation.

The project entails forest conservation efforts that will result in Climate, Community, and Biodiversity benefits in the Sundarban Tiger Reserve's core and buffer zones. It consists of the activities that reduce emissions from forest degradation (Fuel wood/Charcoal) and, the activities to restore the tidal wetlands (under WRC category). The project will result in enhancing carbon sequestration by taking appropriate preventive measures for drivers and curbing forest degradation and aims to prevent further degradation by providing local people with alternative means to support their lives like LPG or improved cook stoves distribution and by providing opportunities to contribute and cooperate in conservation and afforestation activities. The activities include emission reduction in the mangrove forests (REDD+) and tidal wetland restoration under the category wetland restoration and conservation (WRC). The project-crediting period will be of 30 years. The project will generate the credits after every five years i.e., after completion of the monitoring cycle.

Finance through carbon-related projects could be an effective solution to address the point of financial constraints. The incentive generated from carbon finance projects will create additional source of income for the forest-dependent communities, thereby reducing the pressure on forest, leading to conservation and preservation of the ecosystem services. In addition, it would also help in exploring energy-efficient technologies and alternative fuel options in and around the Tiger Reserves thereby reducing carbon emissions. The benefits that result from investment in tiger reserve, includes employment generation, fishing, fodder, fuel wood, carbon sequestration, water provisioning, water purification, sediment retention/soil conservation, nutrient retention, biological control, pollination, gas regulation, climate regulation, gene pool protection, moderation of extreme events, cultural heritage, recreation, spiritual tourism etc.

Objective

The objective of this report is to document the necessary reports and its analysis that are required for the baseline study of the project. This report includes geographical boundaries, temporal boundaries, sampling design and data collected from the project area. With temporal data, the change in the characteristic of the project area for the year 2006, 2010, 2016, 2018 and 2022 is analysed.

Current work integrates field inventory data with satellite images. Analysis involves four major steps, namely, (i) Field data Collection that was done in March, 2022 and Observed Biomass Calculation from the field data, (ii) Satellite Image processing for Land Cover Change and Forest Density Change Detection, (iii) Derivation of vegetation indices using satellite imagery and (iv) Regression Model development based on the relationship between field measured biomass and vegetation index derived from satellite data to estimate historical change in carbon stock.

It also addresses the details about the sampling technique used for calculating the possible number of sample plots, methodology used for estimation of biomass, and geo-location of sample plots in the project area. This report gives a brief description of the current progress of the carbon finance project and the data collected will be used for estimating the baseline conditions using regression model.

Project Area

Sundarban Tiger Reserve Sundarbans lies a little south of Tropic of Cancer between the latitudes $21^031'$ and $22^031'$ North and longitude $88^010'$ and $89^051'$ East.

It is situated in the coastal districts of West Bengal, i.e., South 24- Parganas and part in North 24-Parganas. It lies at the southern-most extremity of the lower Gangetic delta bordering the Bay of Bengal. The Sundarbans can be described as a maze of estuaries, river channels, and creeks encompassing a number (105) of islands of various shapes and sizes. It is the only mangrove forest throughout the world (besides Bangladesh) to harbour significant tiger population. Apart from the tiger, the Sundarban Tiger Reserve also has a rich array of biodiversity values, both floral and faunal. The Sundarbans Tiger Reserve is bound on the east by the international boundary with Bangladesh formed by the rivers Harinbhanga, Raimangal and Kalindi. On the south lies the Bay of Bengal. The western border is formed by the river Matla, which acts as a common boundary with the territorial Forest Division of South 24- Parganas. Towards the north-west, the area is bound by rivers Bidya and Gomdi.

The Tiger Reserve comprises of an area of 2585 sq. km (258500 ha). The legal status of the Reserve is as follows:

1. Sajnekhali Wildlife Sanctuary: 362.40 sq. km.

2. The Sundarban National Park: 1330.10 sq. km.

3. Reserve Forest: 892.43 sq. km.

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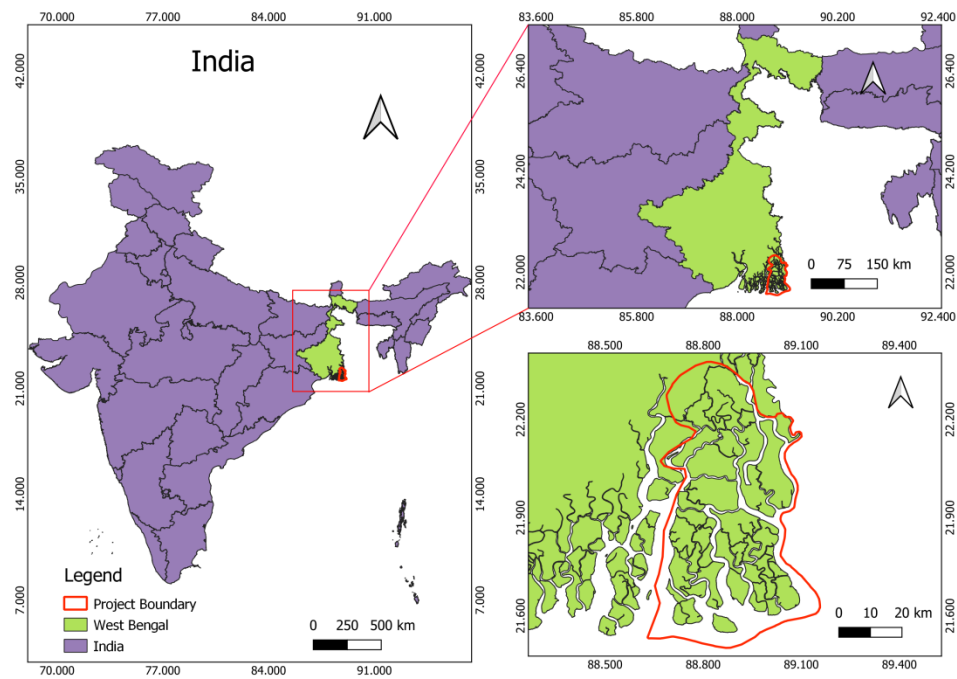
Figure 1 Project location
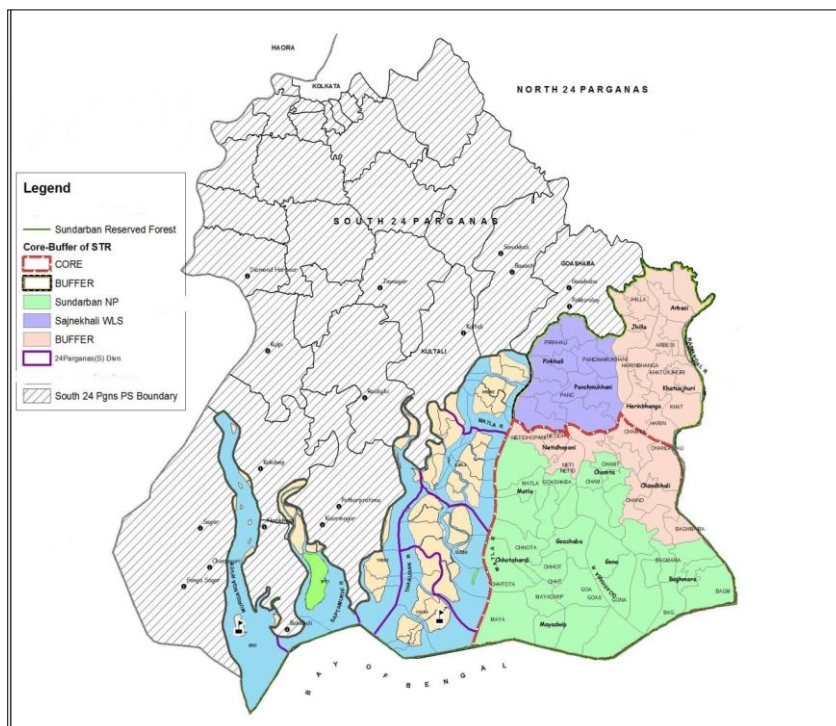
Figure 2 Map of Sundarban Tiger Reserve
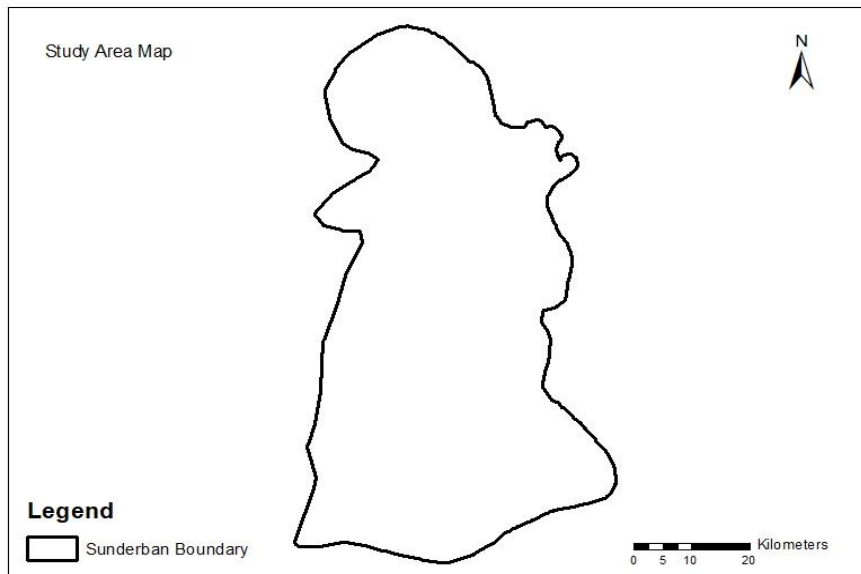
Figure 3 Boundary of the Sundarban Tiger Reserve

The core zone is divided and demarcated into three zones: Critical Tiger Habitat Zone, Zone of International Boundary and Habitat Management Zone. There are no villages within the Tiger Reserve boundary, but there are 62 fringe villages, out of which 24 are situated within the 5 Km radius of the boundary.

A strict protection regime with intensive patrolling is the main project intervention in Critical Tiger Habitat Zone. The area is vulnerable to illicit tree felling, honey collection and poaching of wild animals. Management strategies like joint patrolling and BSF camps are the primary interventions in this zone. The project activities for GHG emission reduction and sequestration consist of REDD and WRC activities.

Delineation of Project Boundary

The delineation of selected study area was done by using permanent boundary markers like rivers or creeks, mountain ridges, etc. to get a permanent boundary of the project area. For the purpose of stratification of the project area, tools like satellite images, aerial photographs, Global Positioning System (GPS) tracking, topographic maps, data of Land use and land cover were used for the preparation of LULC and Forest Density maps. With the help of geo coordinates, a base map for the project area was prepared. Based on this base map, project area was calculated. The project area was verified in the field during the ground truthing. Project boundary was demarcated using field survey as well as google earth imagery to facilitate accurate measuring, monitoring, accounting, and verification of the project activities.

Selection of Data Sets

The temporal boundaries of the project are as follows:

- Project start Date: 1st August 2018

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- Historical Reference Period: (2006, 2010 and 2016)
- Project Crediting Period: 30 years

As per the methodology, the starting date of the historical reference period must be between 9 and 12 years in the past and the end date must be within two years before project start date. The project start date is in 2018. Therefore, 3 timelines have been considered for Historical Change Analysis i.e., 2006, 2010 and 2016.

Development of Maps

Geographic Information System and integration of the same with Remote Sensing data so as to yield good results in classification and quantification of land use units for the study area. In this report Remote Sensing and GIS gives detailed ground information of land use /land cover mapping of the project area.

For generating the LULC and Forest Density Maps, Satellite imagery from Landsat 5 and Landsat 8 for the years 2006, 2010, 2016 and 2018 were used.

For 2006, 2010 the Landsat 5 (TM) data while for 2016 and 2018, the Landsat 8 (OLI/ data downloaded from United States Geological Survey (USGS) Earth Explorer has been used in this study for LULC and Forest Density mapping. The spatial resolution of Landsat TM data and OLI/TIRS data were 30 m). The data were downloaded for same season of the each study year, i.e. November or December months.

The details of the satellite images have been documented in the table below.

Table 1: Detailed information of Satellite Imagery used

Data Source	Type	Resolution	Path/ Row	Acquisition Date	Sensors	Coordinate System and Pre-Processing	Main Use of Data
Landsat 5	Multispectral	30 m	138/45	12 Dec, 2006	TM	WGS_1984_UTM_Zone_45N	LULC, Forest Density
Landsat 5	Multispectral	30 m	138/45	23 Dec, 2010	TM	WGS_1984_UTM_Zone_45N	LULC, Forest Density
Landsat 8	Multispectral	30 m	138/45	21 Nov, 2016	OLI	WGS_1984_UTM_Zone_45N	LULC, Forest Density
Landsat 8	Multispectral	30 m	138/45	13 Dec, 2018	OLI	WGS_1984_UTM_Zone_45N	LULC, Forest Density
Landsat 8	Multispectral	30m	138/45	21 Oct,2022	OLI	WGS_1984_UTM_Zone_45N	LULC, Forest Density

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Table 2 Bands and resolution of Satellite Imagery

Band No.	Resolution	Band Name	Wavelength (micrometers)	
			TM	OLI
1	30 m	Blue	0.45-0.52	0.45-0.51
2	30 m	Green	0.52-0.60	0.53-0.59
3	30 m	Red	0.63-0.69	0.64-0.67
4	30 m	NIR	0.76-0.90	0.85-0.88

Processing of Remote Sensing Data

Image Correction

The task used multi-spectral data from Landsat series for Land Use Land Cover (LULC) and forest cover density mapping. The geometrically co-registered (with sub-pixel accuracy) open-source cloud free Landsat data form the main data for our analysis. The Landsat images with least cloud cover were downloaded from the United States Geological Survey (USGS) portal. The standards False Colour Composite (FCC) of satellite remote sensing (Landsat) data were prepared.

Landsat dataset used are processed to Systematic Terrain Correction (L1GT) which is created when the systematic product has consistent and sufficient locational accuracy to permit the application of a terrain model. The L1GT provides systematic, radiometric, and geometric accuracy, which employing a Digital Election Model (DEM) to correct for relief displacement. The accuracy of these data products is attributed pointing accuracy of the spacecraft, and thus terrain correction helps to account for the higher order/relief induced distortion event when GCP are not used, thus it is typically better than one pixel.

The pre-processing of Landsat data includes following steps: - firstly, all the datasets were geometrically corrected using map projection Universal Transverse Mercator (UTM) coordinate system using World Geodetic System 1984 (WGS84) datum and spheroid by the USGS. Further, the Normalized Difference Vegetation Index was computed using equation (NDVI = NIR - Red/NIR + Red) and layer staked with the original bands. The NDVI formula combines the information available in the red and NIR bands into a single and representative value. NDVI is helpful in assessing the vegetation health and stress. Also, the combination of NDVI with Red and NIR bands enhances the satellite data for differentiating vegetation classes from non-vegetation classes.

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The standards False Colour Composite (FCC) of satellite remote sensing (Landsat) data were prepared.
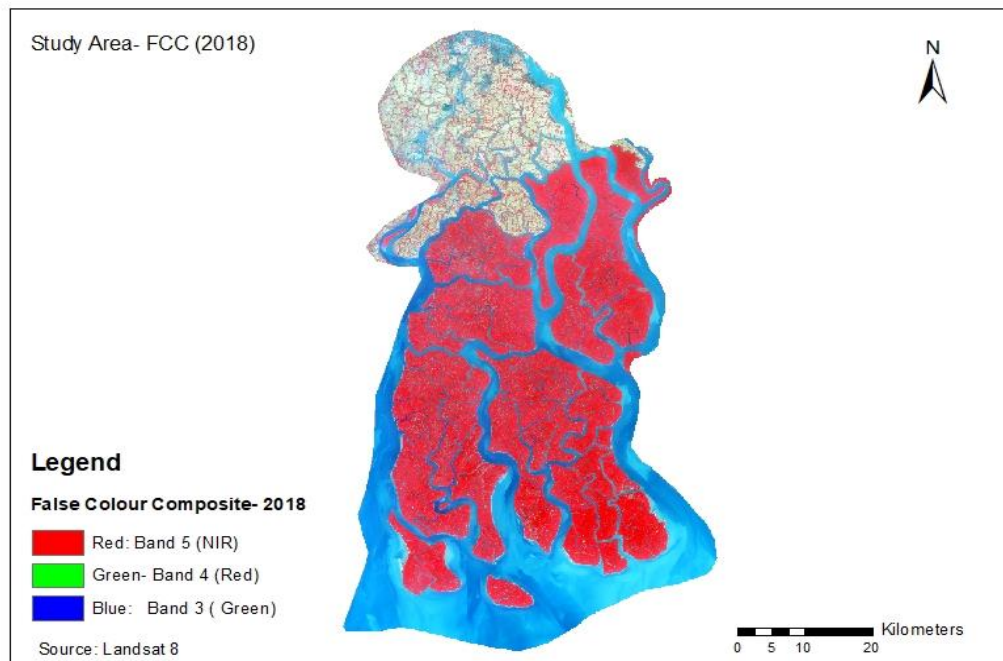
Figure 4 False Colour Composite imagery of Sundarban Tiger Reserve

False colour images are a representation of a multi-spectral image produced using bands other than visible red, green and blue as the red, green and blue components of an image display. False colour composites allow us to visualize wavelengths that the human eye cannot see (i.e. near-infrared). Using bands such as near infra-red increases the spectral separation and often increases the interpretability of the data. There are many different false coloured composites which can highlight many different features The given False Colour Composite Fig. 3 of the project study area i.e., Sundarban Tiger Reserve. The red colour represents vegetation of the area, the blue colour depicts the water bodies and white-greyish part represents the habitation i.e., Villages around the Sundarban Tiger Reserve.

LULC Classification

A thorough scanning of earlier published literature and maps on LULC of the Sundarban Tiger Reserve was carried out including the information available with the State Forest Department. Google Earth Images and Landsat Satellite data were reviewed for different seasons and dates to define a classification scheme for satellite data classification. Using outcomes of the review of published literature, forest inventory reports from State Forest Department, land use and eco-zones maps, distribution of biomes and protected area, and taking account of the focus of the study, a classification scheme was designed to assess the satellite data for mapping LULC. The classification scheme proposed by Biodiversity Characterization at Landscape Level (Department of Space – Department of Biotechnology imitative) was used to develop a classification scheme for the present work. For the forest cover density mapping, the classification scheme followed by the Forest of Survey of India (FSI) in the India State of Forest Report (ISFR) was referred. The proposed classification

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scheme offers consistency owing to the LULC distribution in the study region. Each class is mutually exclusive hence there are least chances of confusions and overlaps.

In addition to information gathered from active and systematic ground truth (carried out during the sampling) across the study region, the study has relied on Google Earth images for collection of reference data. Satellite data (in standard False Colour Composite using NIR, Red and Green, and True Colour Composite using Red, Green and Blue) along with Google Earth Images of very high resolution were reviewed. In absence of ground truth and a-priori knowledge, no statistical tools/sampling strategies were used. Instead, the maximum possible training sets were generated using the Google Earth images to have better control over the image for classification. While reviewing, the scales of 1:50,000 were kept constant. Using the classification scheme defined above, areas which could be potentially used for the training and testing sets were identified on the satellite data. The exercise was independently carried out for the years 2006 through 2018. These were further checked with the published maps and literature including the field photographs on the Google Earth and other websites. Area/Region of Interest (A/ROI) polygons were generated for each of the validated site on the Landsat data while referring to the Google Earth images. The distribution is roughly proportional (around 0.005 % to 0.01% of the area) to the area covered by the respective classes, availability of photographs and focus of the study for the mapping exercise. The forest cover density mapping was carried out using NDVI images and consistent interactive interpretation from FCC and Google Earth Images.

LULC Maps

Here, broadly a total of ten LULC classes have been identified namely Water body 1, Aqua Culture, Swamp, Mangrove 1 (*Avicennia alba* dominant), Mangrove 2 (Avicennia mixed) Scrubland, Agriculture, Water body 2, Other vegetation and Built up.
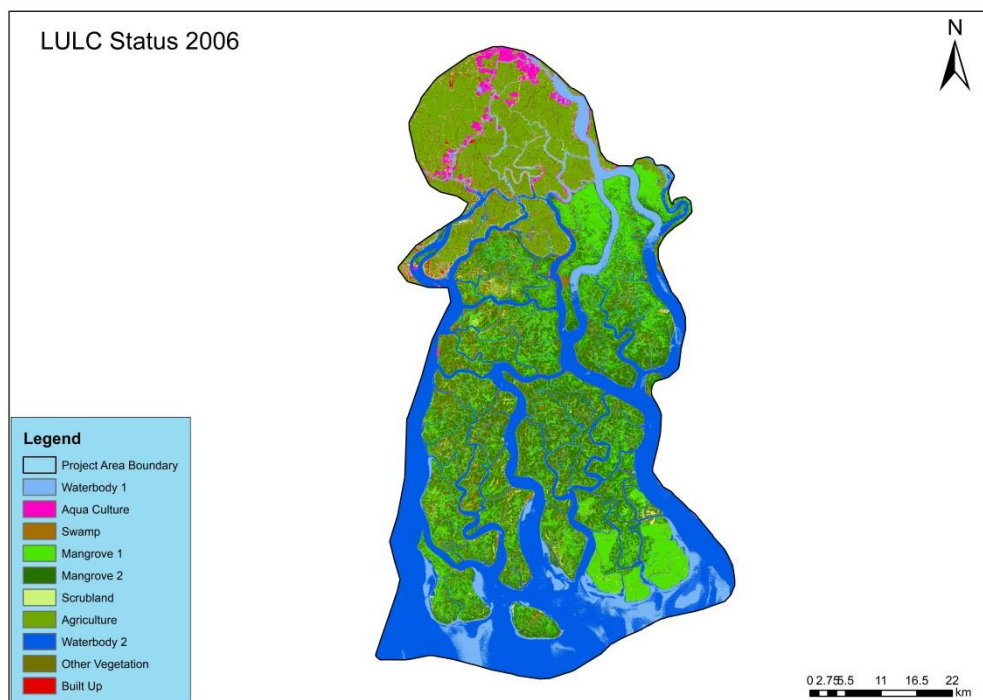
Figure 5 LULC map of Sundarban Tiger Reserve 2006

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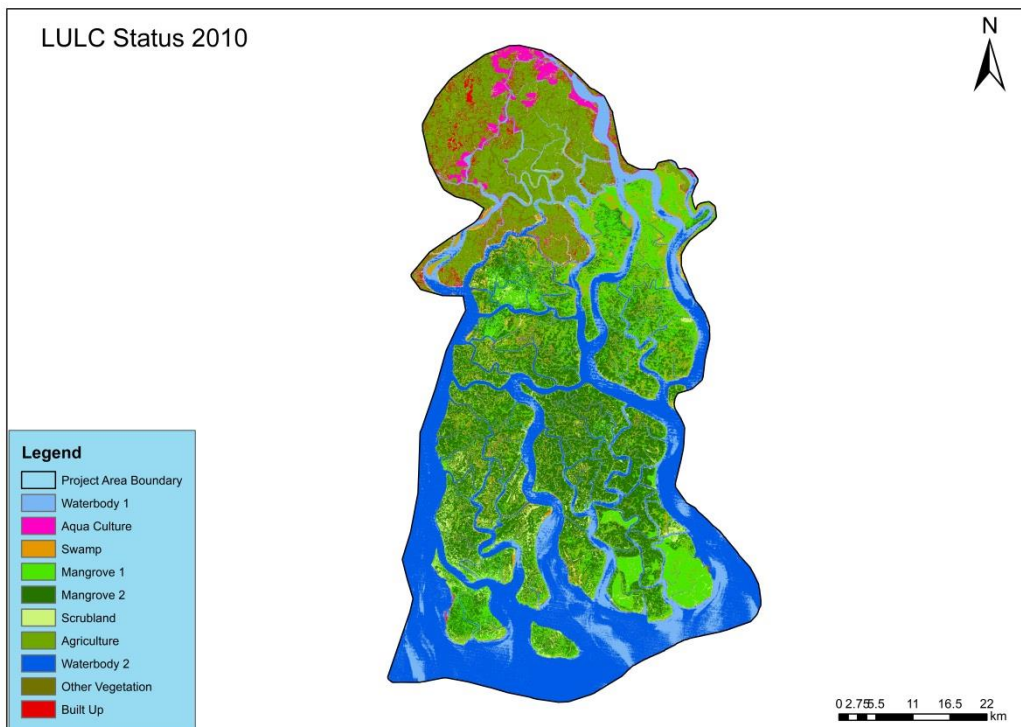
Figure 6 LULC map of Sundarban Tiger Reserve 2010
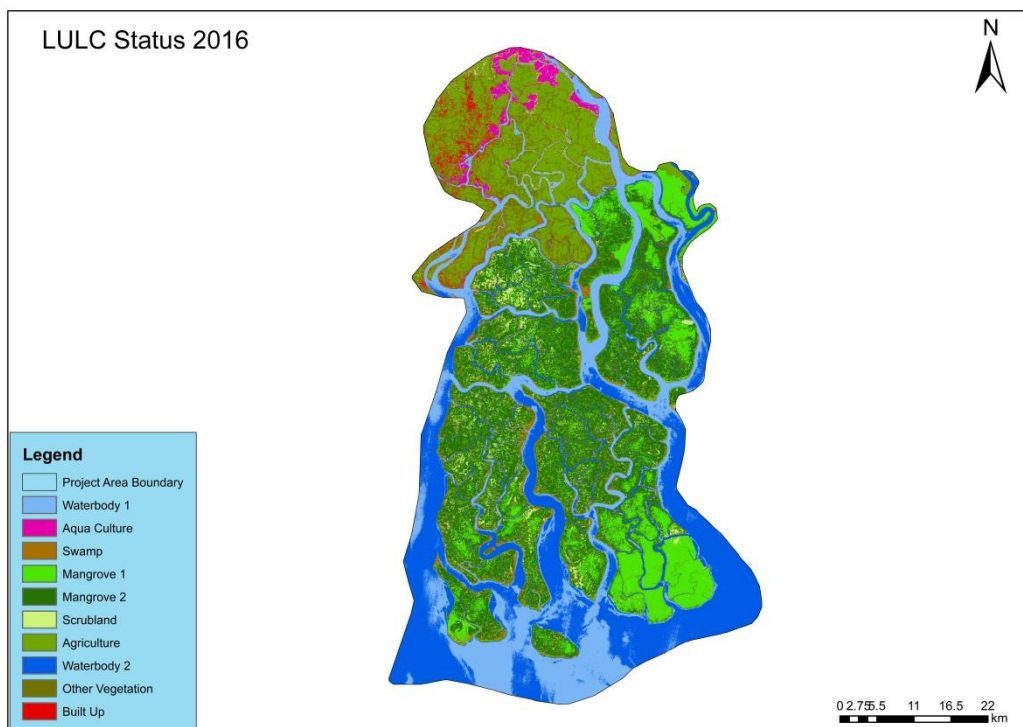
Figure 7 LULC map of Sundarban Tiger Reserve 2016
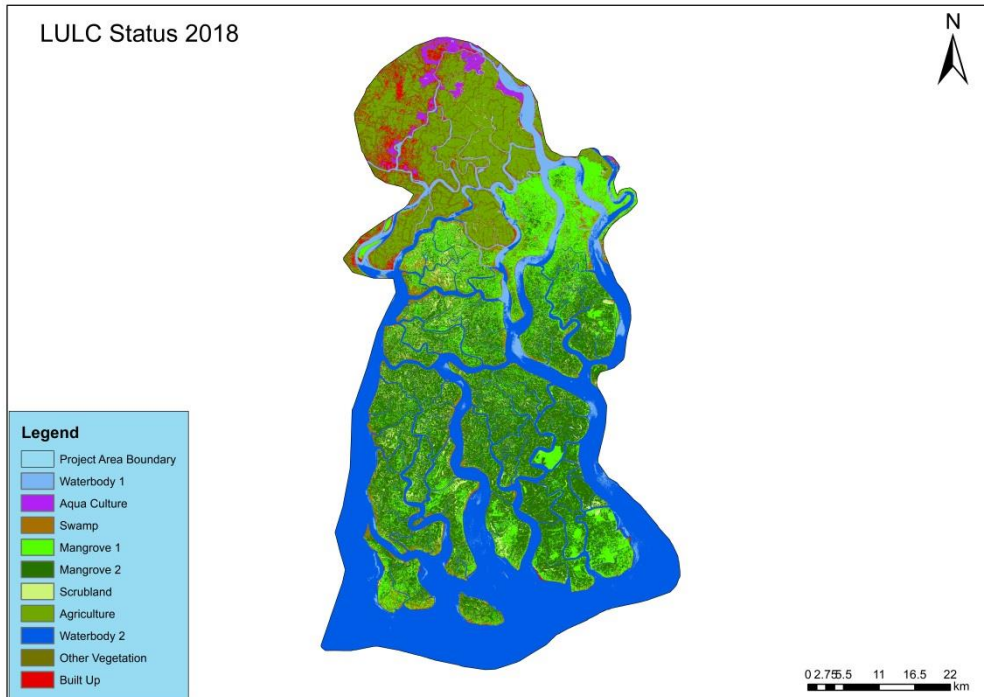
Figure 8 LULC map of Sundarban Tiger Reserve 2018
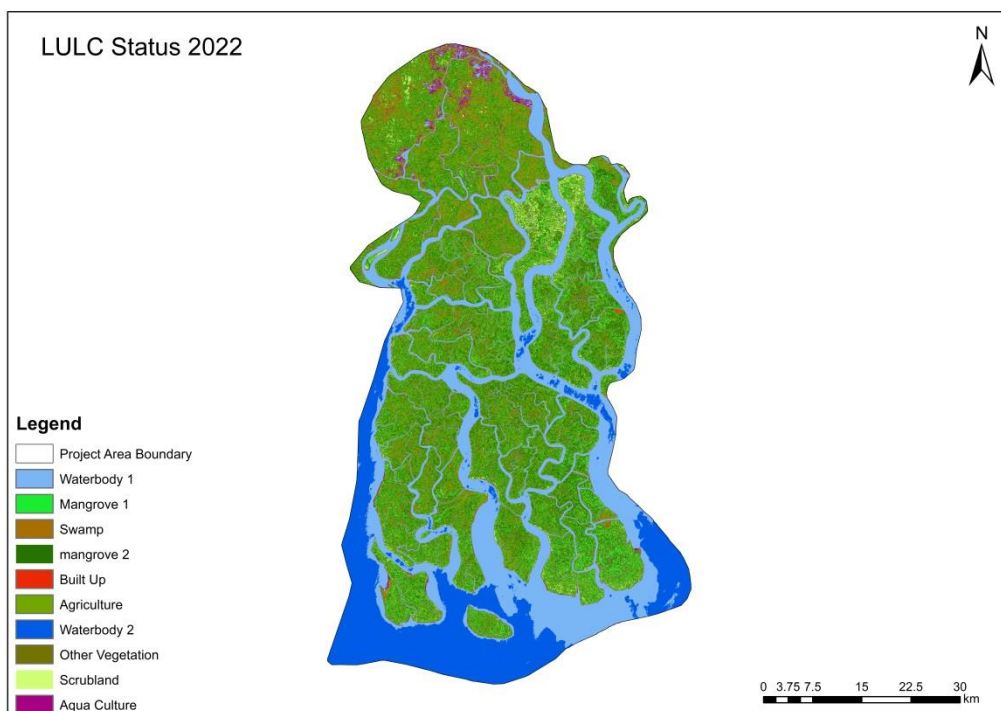
Figure 9 LULC map of Sundarban Tiger Reserve 2022

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The area coverage and percentage of each LULC for the periods including 2006, 2010, and 2016 , 2018 and 2022 are summarized in Table 3 and 4.

The LULC classification for the TM 2006 image shows that the other vegetation and built up covering for about 134.97 sq. km (3.79%). Agriculture and Scrubland covered an area of 372.07 sq. km (10.43%) and 174.85 sq. km (4.90%) respectively, whereas the area coverage of Waterbody 1, Waterbody 2 and Aqua Culture were 257.35 sq.km (7.21%) and 1085.44 sq.km (30.42%) and 52.77 sq.km (1.48%) of the total area of the project area. Whereas, in 2018, other vegetation and built up covering for about 206.64 sq. km (5.79%). Scrubland and Agricultural land covered an area of 148.31 sq.km (4.16%) and 354.06 sq. km (9.92%) respectively, whereas the area coverage of Waterbody 1, Waterbody 2 and Aqua Culture were 176.19 sq.km (4.94%) and 1194.02 sq.km (33.46%) and 42.64 sq.km (1.19%). (Table 3 and 4)

Table 3 Current and historical LULC area matrix

S. No.	LULC class	Years/ Area under each class (sq. km)				
		2006	2010	2016	2018	2022
1	**Waterbody 1**	257.35	356.29	584.74	176.19	502.6032
2	**Aqua Culture**	52.77	59.56	50.35	42.64	73.215
3	**Swamp**	239.93	173.73	170.74	185.5	101.2194
4	**Mangrove 1 (*Avicennia alba* dominant)**	575	503.01	390.96	443.58	647.7192
5	**Mangrove 2 (*Avicennia* mixed)**	676.15	730.52	884.69	817.58	710.2917
6	**Scrubland**	174.85	230.04	148.88	148.31	113.5791
7	**Agriculture**	372.07	378.1	360.69	354.06	363.0087
8	**Waterbody 2**	1085.44	979.66	782.67	1194.02	851.5134
9	**Other vegetation**	119.37	111.91	157.2	146.92	121.8195
10	**Built up**	15.6	45.7	37.59	59.72	83.5488
Total		**3568.53**	**3568.52**	**3568.51**	**3568.52**	**3568.52**

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Table 4 Area percentage of LULC type

S. No.	LULC class	Years/ Area Percentage under each class				
		2006	2010	2016	2018	2022
1	Waterbody 1	7.21	9.98	16.39	4.94	14.08
2	Aqua Culture	1.48	1.67	1.41	1.19	2.05
3	Swamp	6.72	4.87	4.78	5.20	2.84
4	Mangrove 1 (*Avicennia alba* dominant)	16.11	14.10	10.96	12.43	18.15
5	Mangrove 2 (*Avicennia* mixed)	18.95	20.47	24.79	22.91	19.9
6	Scrubland	4.90	6.45	4.17	4.16	3.18
7	Agriculture	10.43	10.60	10.11	9.92	10.17
8	Waterbody 2	30.42	27.45	21.93	33.46	23.86
9	Other vegetation	3.35	3.14	4.41	4.12	3.41
10	Built up	0.44	1.28	1.05	1.67	2.34
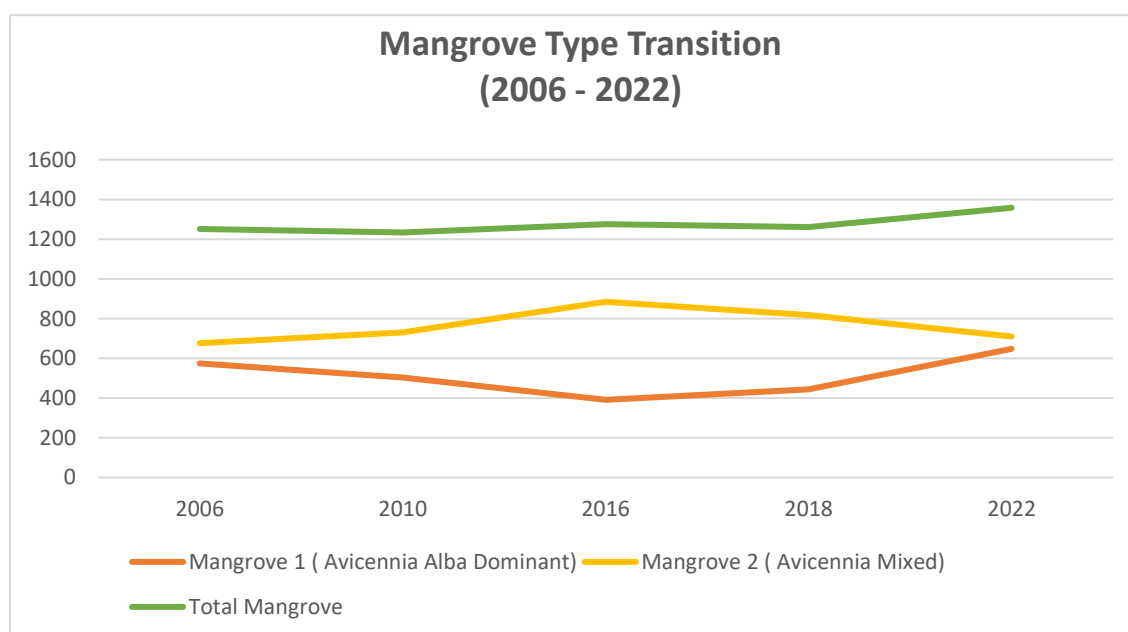
Figure 10 Mangrove Type Transition (2006-2022)

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In 2018 area total occupied by the mangrove forest in the project area was 1261.16 sq.km. In the year 2022 the area covered by the mangrove forest increased to 1358.01 sq.km of the project area. (Table 3)

Figure 10 clearly indicates that the interventions had an impact on the increment of forest cover by 7.6 percent.
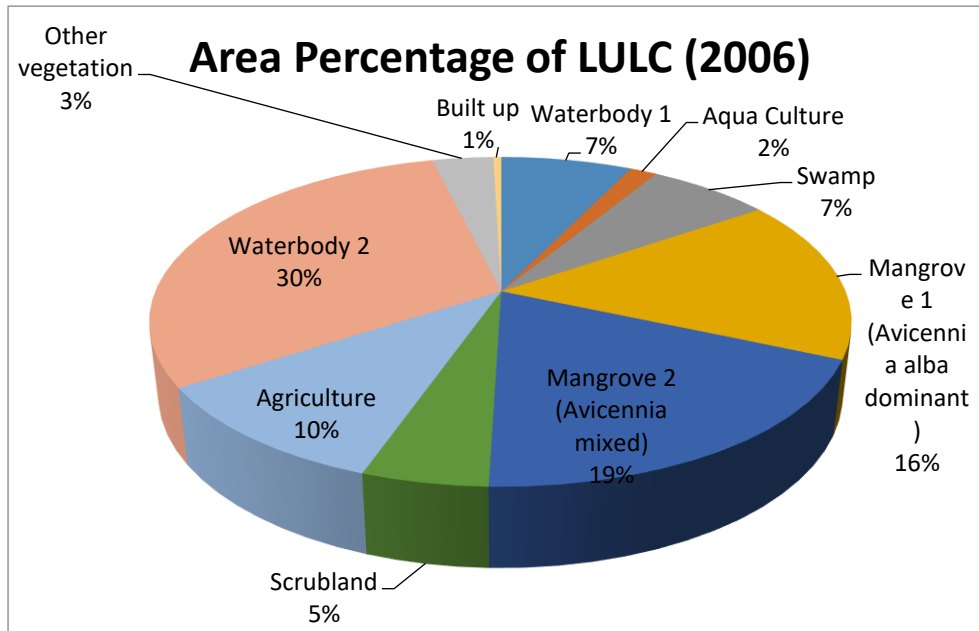
Figure 11 Area Percentage of LULC 2006
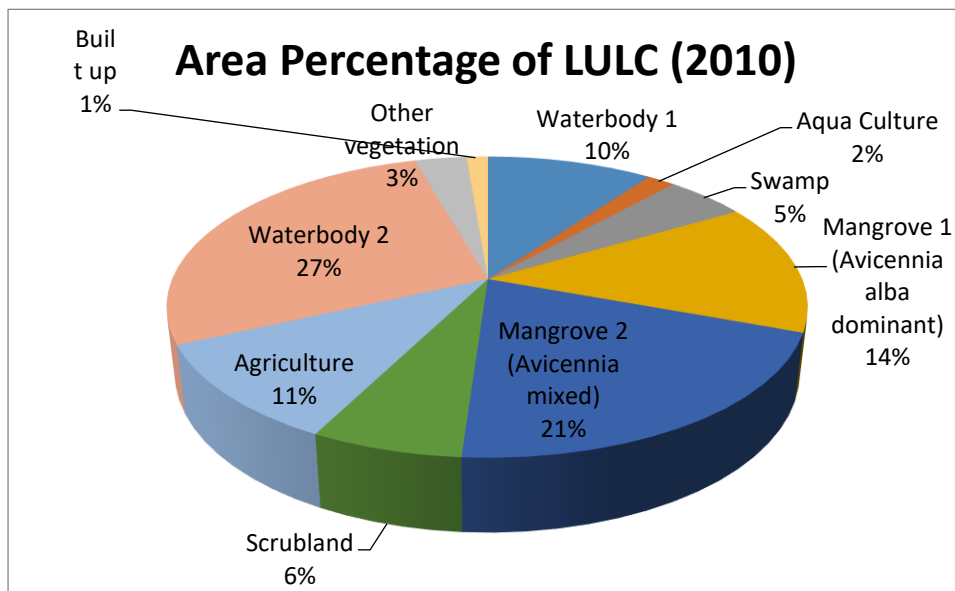
Figure 12 Area Percentage of LULC (2010)

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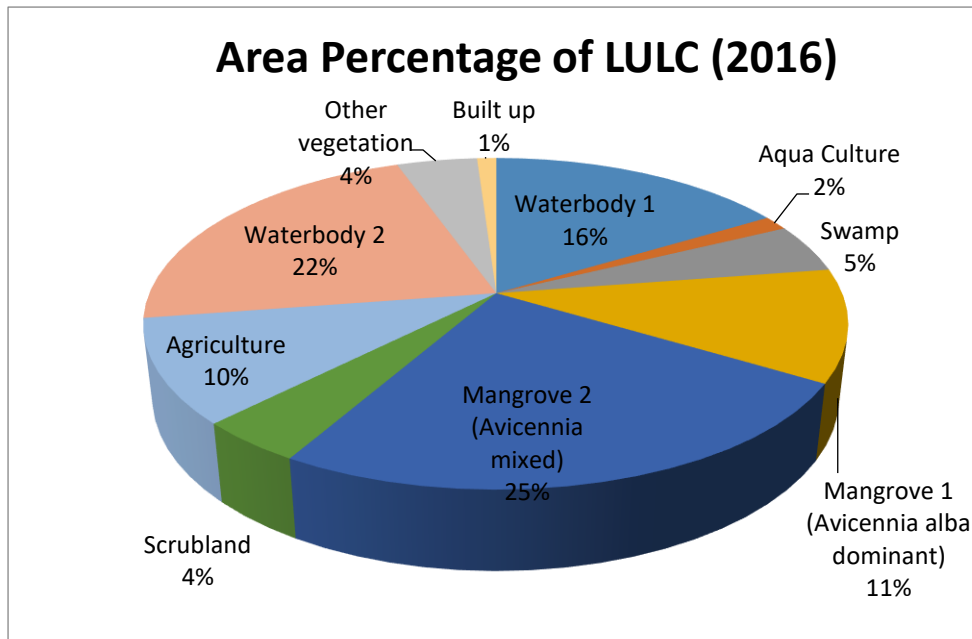
Figure 13 Area Percentage of LULC (2016)
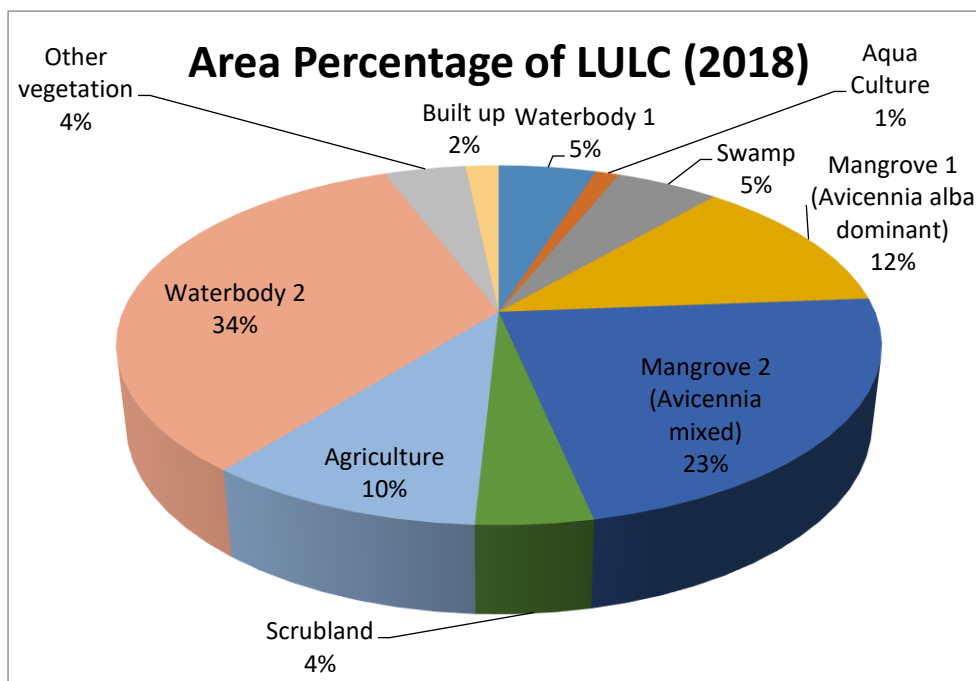
Figure 14 Area Percentage of LULC 2018

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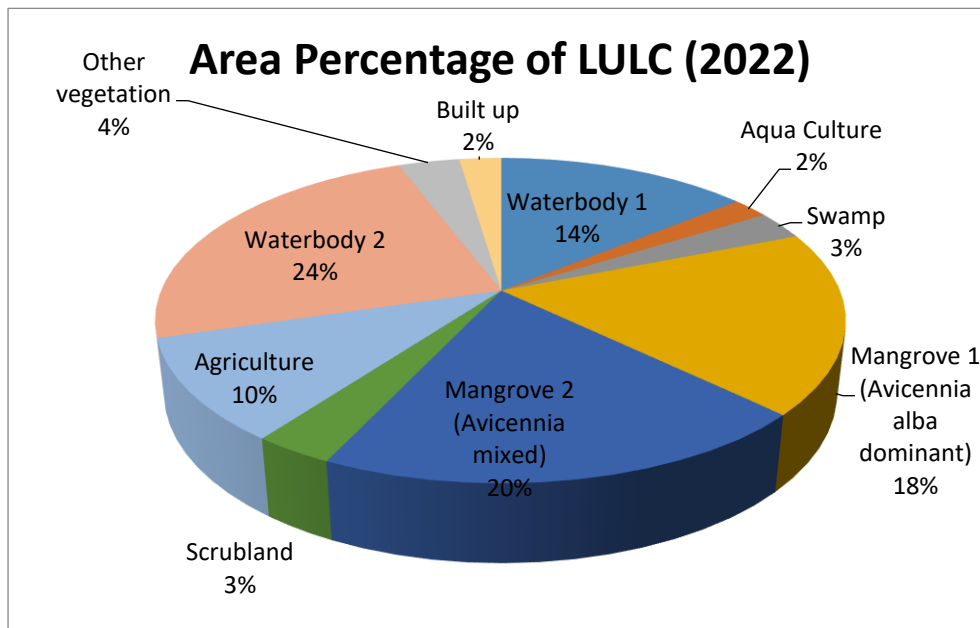
Figure 15 Area Percentage of LULC 2022

Forest Density Maps

For Forest density, here the project area is divided into four major groups i.e., Non-Forest Area, Scrub, Open Forest, Moderately Dense Forest and Dense Forest.
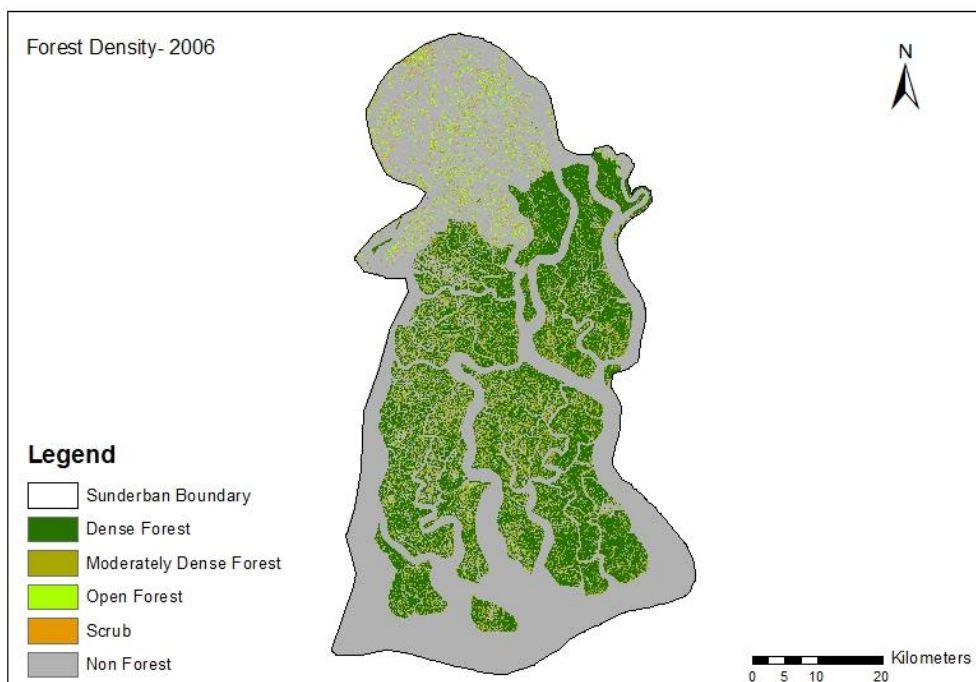
Figure 16 Forest Density Map of Sundarban Tiger Reserve (2006)

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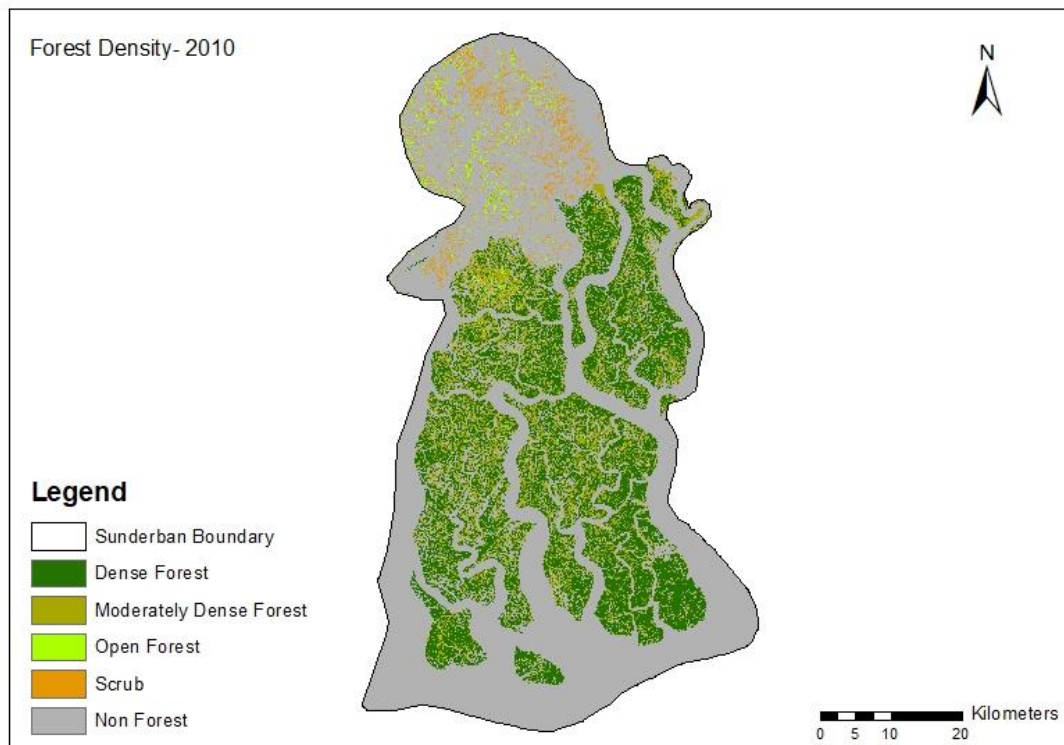
Figure 17 Forest Density Map of Sundarban Tiger Reserve (2010)
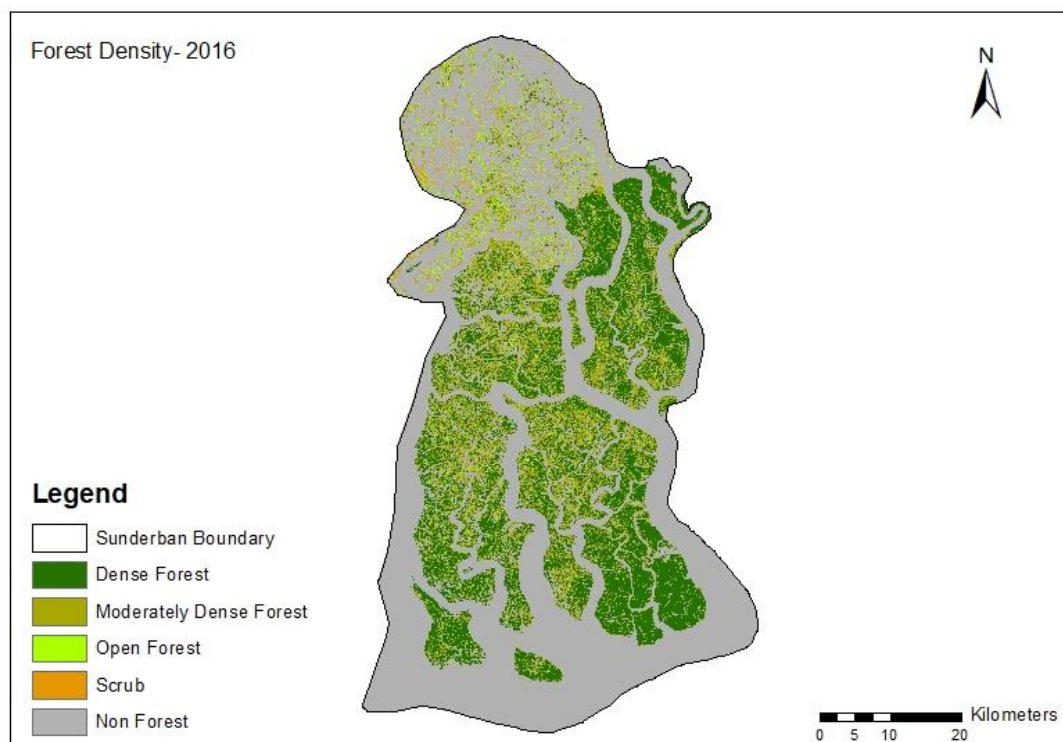
Figure 18 Forest Density Map of Sundarban Tiger Reserve (2016)
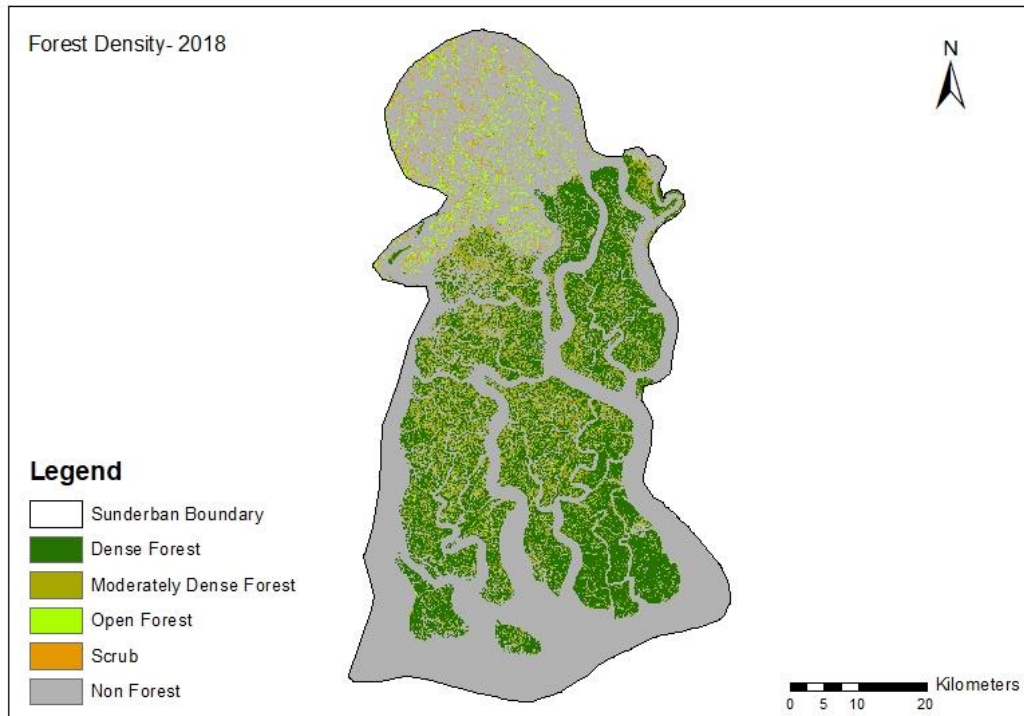
Figure 19 Forest Density Map of Sundarban Tiger Reserve (2018)

 Figure 20 Forest Density Map of Sundarban Tiger Reserve (2022)

The area and percentage of forest density for the periods including 2006, 2010, and 2016, 2018 and 2022 are summarized in Table 5 and 6.

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Table 5 Current and historic Forest Density Change

Class	2000	2006	2010	2016	2018	2022
Non Forest	2193.55	2198.00	2223.08	2135.66	2160.35	1913.85
Scrub	40.81	11.86	72.70	33.03	45.95	63.37
Open Forest	94.10	68.65	43.43	82.32	96.31	104.09
Moderately Dense Forest	276.09	318.31	371.01	515.29	361.48	424.04
Dense Forest	963.95	971.68	858.28	802.20	904.32	1063.15
Total	3568.51	3568.51	3568.51	3568.51	3568.43	3568.51
Forest Area	1334.15	1358.65	1272.72	1399.81	1362.12	1591.28

Area (sq. km)
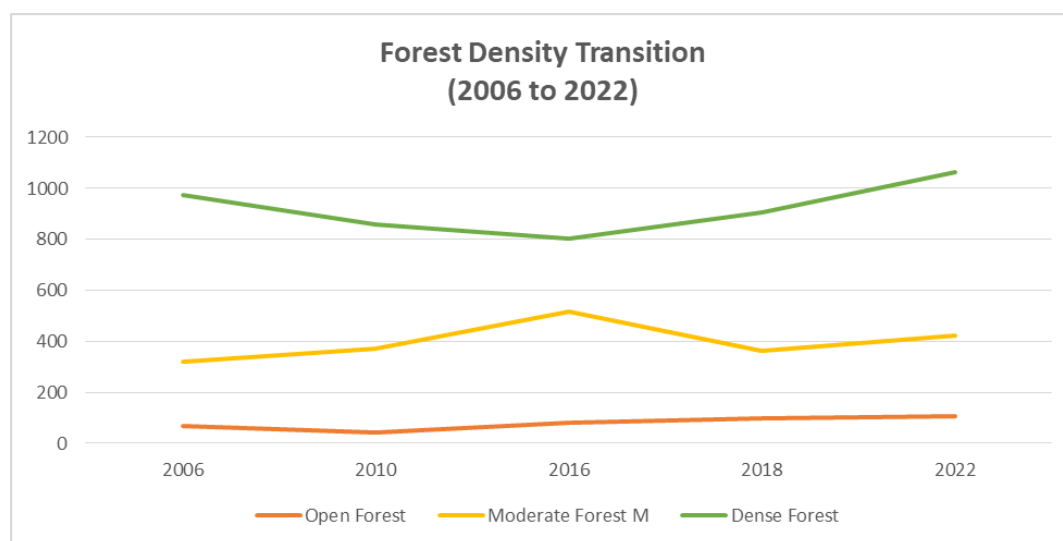
Figure 21 Forest Density Transition (2006 to 2022)

The result, obtained from multi-temporal satellite images through forest density maps, covering major classes such as Non-Forest Area, Scrub, Open Forest, Moderately Dense Forest and Dense Forest of the year 2006, 2010, 2016, 2018, and 2022 are shown in Fig. 16, 17, 18, 19 and 20. In addition, the spatial distribution of each LULC class along with the percentage of the total area occupied by each class is summarized in Table 6.

Result demonstrates that in 2018, 96.31 sq.km of the total land was under open forest 361.48 sq.km under Moderately Dense Forest and 904.32 sq.km of land under Dense Forest. On the other hand, in 2022, 104.09 sq.km areas covered the Open Forest, 424.04 sq.km covered the Moderately Dense Forest and 1063.15 sq.km of area covered the Dense Forest.

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It is clearly evident from the Table 5 that area under the non-Forest in 2018 was 2160.35 sq.km whereas in 2022 it reduced to 1913.85 sq.km. (According to the ISFR 2021, Non-Forest is defined as the land which does not include above mentioned classes such as Open, Moderately Dense, Scrub and Dense Forest).

The result indicates that there is a sharp increase in forest density cover, which is evident from Table 5. It clearly indicates that the interventions had an impact on the increment of forest density. In comparison to the baseline year i.e., 2018 Dense forest Density has been increased by 17.5 percent. Figure 21

Table 6 Forest Density Percentage

Class	2006	2010	2016	2018	2022
Open Forest	5	3	6	7	7
Moderately Dense Forest	23	29	37	27	29
Dense Forest	72	68	57	58	64
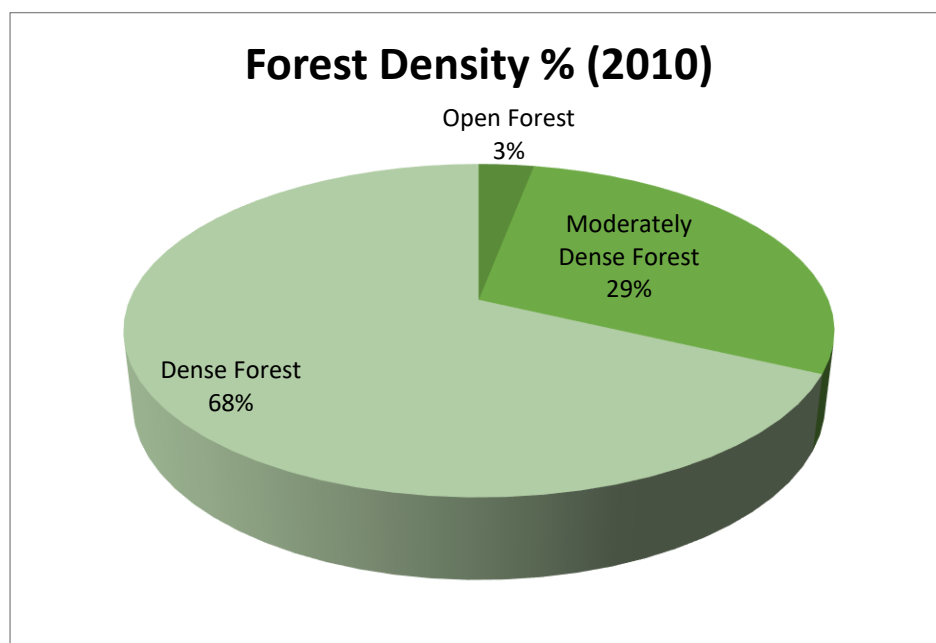
Figure 22 Forest Density Percentage 2006

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Forest Density % (2006)

Open Forest
5%

Moderately
Dense Forest
23%

Dense Forest
72%
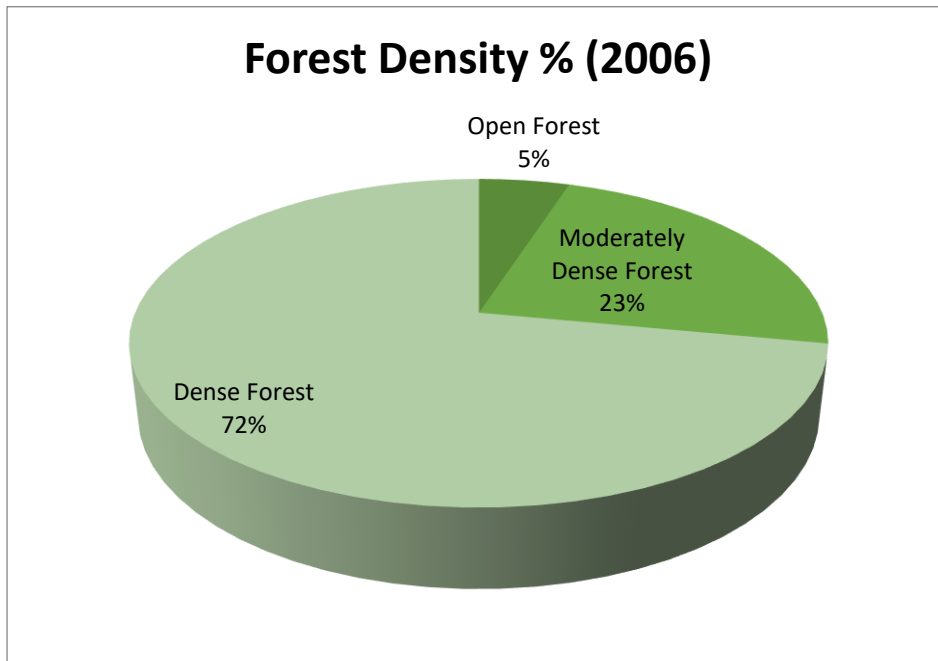
Figure 23 Forest Density Percentage 2010

Forest Density % (2016)

Open
Forest
6%

Moderately
Dense Forest
37%

Dense Forest
57%
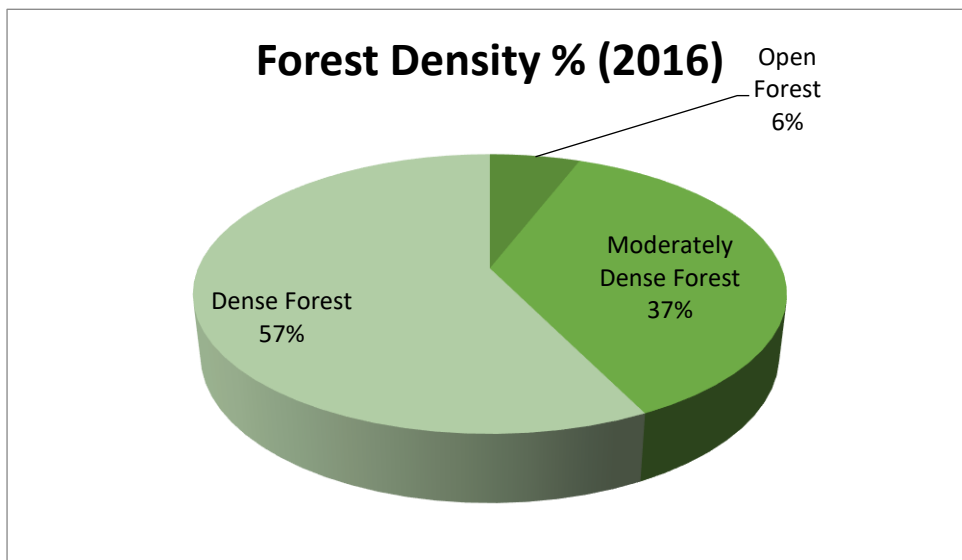
Figure 24 Forest Density Percentage 2016

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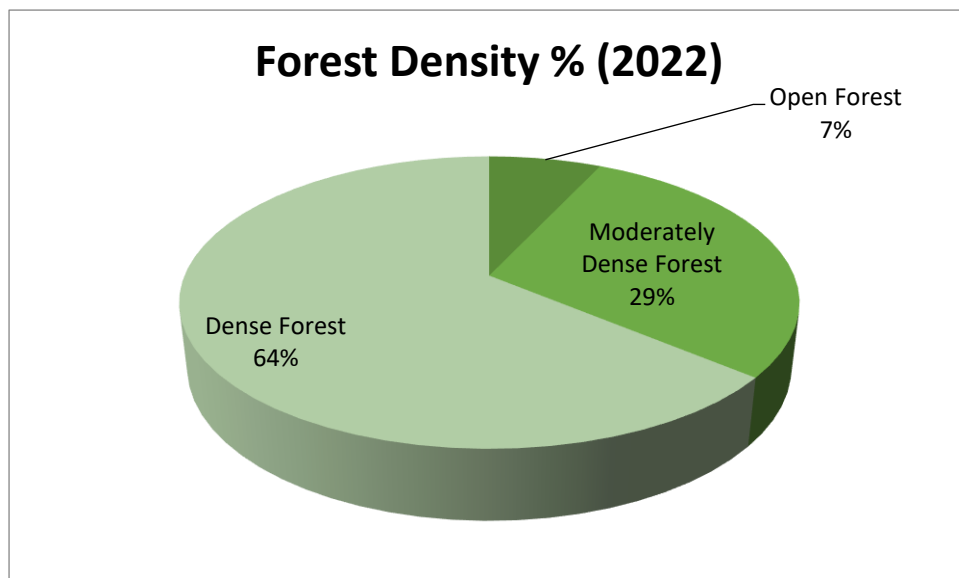
Figure 25 Forest Density Percentage 2018
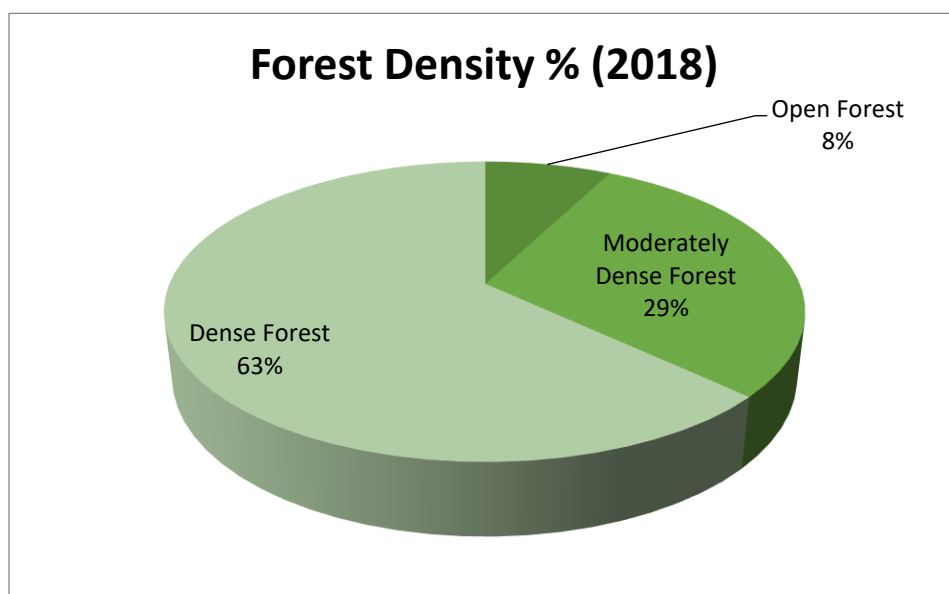
Figure 26 Forest Density Percentage 2022

Other Maps

The vector data set is based on the FAO-UNESCO Soil Map of the World at 1:5 000 000 scale. The data has been processed and converted as raster classes in GIS platform. Mainly two types of soil have been observed in the Sundarban Tiger Reserve. These are Loamy and Clay Skeletal, whereas loamy soil is the majorly dominated soil type in the entire project area. Figure 27

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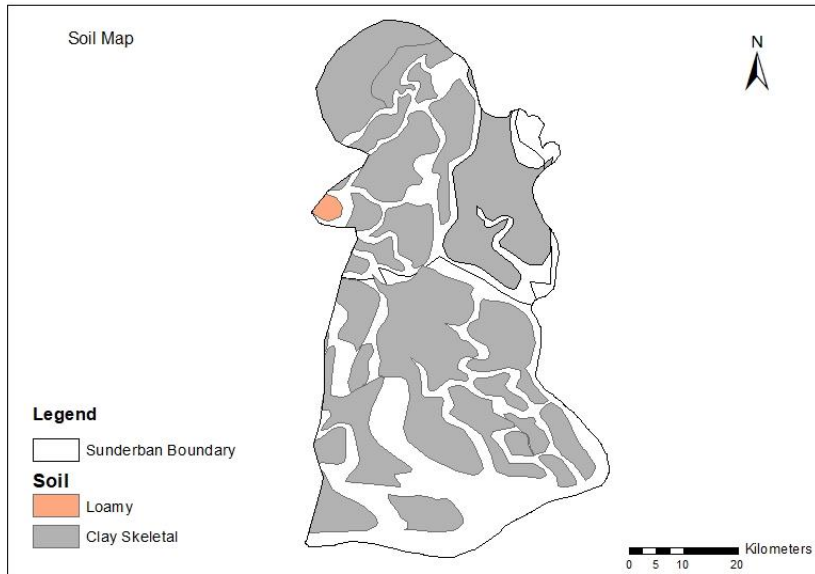
Figure 27 Soil map of the project area (2018)

The elevation and Surface Water river network maps have been prepared using SRTM DEM data having a spatial resolution of 30 meters. SRTM DEM data has been accessed from USGS Earth Explorer Portal. (Figure 28 and 29)
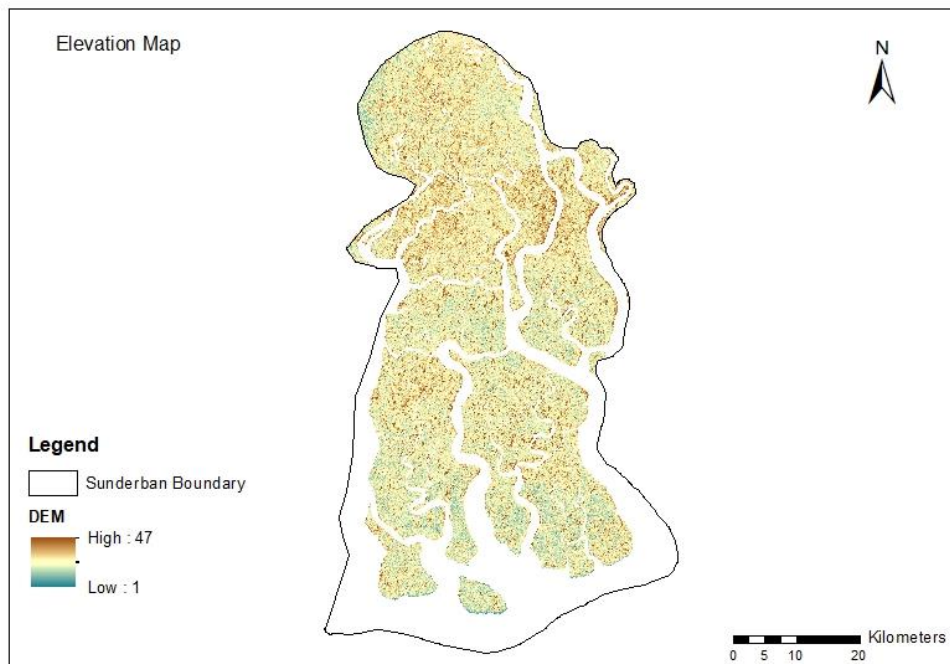
Figure 28 Elevation map of the project area. (2018)

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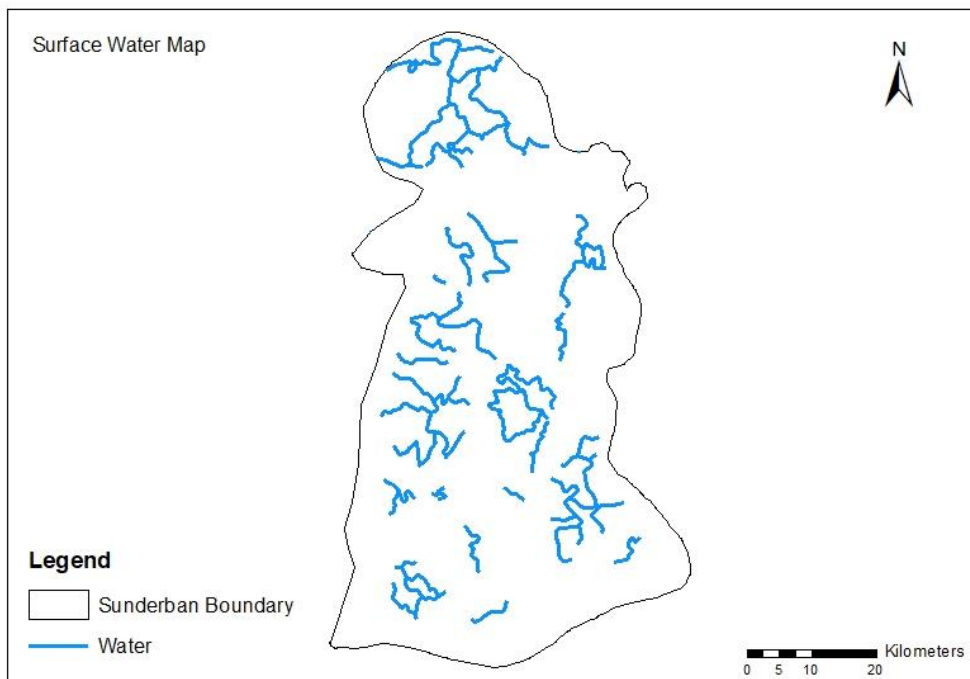
Figure 29 Surface Water river network map of the project area (2018)

Sundarban has a complex drainage pattern made up of interconnected rivers, cross channels, estuaries and heavy seasonal rainfall.

Hugli, Matla, Bidyadhari, Raimangal, Saptamukhi rivers with their tributaries/distributaries from the main drainage in this district.

Major Drainages of Indian Sundarban:

a) Natural- Hooghly Matla, Bidyadhari, Raimangal, Thakuran, Saptamukhi etc.

b) Artificial Bhangar khal, Kulpi khal, Surjapur khal etc.

River Network map for the project area have been prepared using the Hydro river data product. Hydro rivers represents a vectorized line network of all global rivers that have a catchment area of at least 10 km or an average river flow of at least 0.1 m /sec, or both. HydroRIVERS has been further extracted from the gridded Hydrosheds core layers at 15 arc-second resolution."

Historical Change Analysis

An important aspect of change detection is to determine what is actually changing to what category of LULC type (i.e., which LULC type is changed to the other type of LULC class). LULC changes matrix depicts the direction of change and the LULC type that remains as it is at the end of the period. Thus, to clearly understand the source and destination of major LULC changes, change matrix for each period was analysed. For change analysis, change matrices were generated for the different time periods to analyse changes in the area covered by different LULC classes. This was done by comparing the number of pixels falling

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into each category of LULC/forest cover density in one time-period with the categorization of the same pixels in same/different class in the previous time-period.

Change in classes = MATRIX (time 1, time 2)

The data gathered from the generated matrix was further rearranged to prepare the change matrix. Two change maps were prepared for these four time periods by overlaying LULC maps of two successive time periods. Changes in LULC classes between two years were analysed through the change maps generated.

The extent and rate of changes of each LULC for the three periods including 2006, 2010, 2016, 2018 and 2022 are summarized.

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Table 7 Land Use Land Cover Change matrix for 2006-2010

	Class	2010 (Area Sq.Km)									
		Waterbody 1	Aqua Culture	Swamp	Mangrove 1 (*Avicennia alba* dominant)	Mangrove 2 (*Avicennia* mixed)	Scrubland	Agriculture	Waterbody 2	Other vegetation	Built up
2006	Waterbody 1	137.31	4.15	0.09	0.00	0.00	1.44	1.09	112.87	0.25	0.11
	Aqua Culture	6.58	37.58	0.18	0.00	0.00	2.21	3.16	1.72	0.48	0.81
	Swamp	0.44	0.20	60.56	21.59	64.55	83.61	1.13	0.57	7.08	0.14
	Mangrove1(*Avicennia alba* dominant)	0.42	0.01	21.79	330.34	213.33	7.70	0.28	0.27	0.78	0.03
	Mangrove 2 (*Avicennia* mixed)	0.91	0.10	40.79	138.59	448.19	45.45	0.38	1.25	0.39	0.06
	Scrubland	3.64	6.91	36.14	9.91	3.21	60.14	24.69	6.35	17.25	6.55
	Agriculture	0.84	3.40	0.75	0.12	0.06	5.56	302.24	0.05	28.66	30.37
	Waterbody 2	205.44	4.70	7.21	0.86	0.12	6.42	1.62	856.46	0.76	1.80
	Other vegetation	0.46	1.46	6.17	1.56	1.03	17.31	32.61	0.047	55.59	3.10
	Built up	0.21	1.00	0.00	0.00	0.00	0.16	10.87	0.019	0.63	2.68

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Table 8 Forest density change matrix for the year 2006-2010

	Class	2010 (Area Sq.Km)				
		Non Forest	Scrub	Open Forest	Moderately Dense Forest	Dense Forest
2006	**Non Forest**	2042.40	44.24	18.52	81.37	11.45
	Scrub	8.38	2.95	0.51	0.00	0.00
	Open Forest	36.46	18.95	12.48	0.69	0.054
	Moderately Dense Forest	83.31	6.49	11.7	157.42	59.31
	Dense Forest	52.51	0.05	0.13	131.51	787.4595

Area (sq. km)

The diagonal cells of the matrix in the above tables 7, 8, 9, 10, 11 and 12 represent the area that has remained same in both the time periods. Other cell values represent the area that has changed from one class to another class.

From the above table 7 and 8, it is evident that for land use land cover, about 174.89 sq.km of the area that was covered with Water body 1 and 2 in 2006 remained the same in 2010. 508.34 sq. km of the area that was covered with Mangrove Forest (*Avicennia alba* Dominant) and Mangrove 2 (Avicennia Mixed) in 2006 was still under the same cover in 2010. Around 1216.97 sq.km of scruband, Agriculture, built up and other vegetation of the project area   in 2006 remained the same in 2010. For Forest Density, it is evident that 957 sq. km of project area under the Open, Dense and Moderately Dense Forest in 2006 remained the same in 2010.

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Table 9 Land Use Land Cover Change matrix for 2010-2016

		2016 (Area Sq.Km)									
		Waterbody 1	Aqua Culture	Swamp	Mangrove1(*Avicennia alba* dominant)	Mangrove 2 (*Avicennia* mixed)	Scrubland	Agriculture	Waterbody 2	Other vegetation	Built up
	Waterbody 1	193.49	2.17	2.20	0.09	0.00	1.23	2.07	153.460	1.089	0.448
	Aqua Culture	6.04	40.32	1.86	0.06	0.00	2.11	3.67	2.925	1.488	1.064
	Swamp	0.62	0.11	46.83	34.52	35.22	34.60	8.78	10.760	2.250	0.021
	Mangrove1(*Avicennia alba* dominant)	1.04	0.00	19.43	211.61	255.99	10.63	1.41	2.051	0.808	0.005
	Mangrove 2 (*Avicennia* mixed)	0.03	0.00	33.11	122.51	552.97	21.40	0.14	0.316	0.011	0.001
	Scrubland	4.09	2.32	61.36	20.01	39.18	63.86	11.96	11.579	14.995	0.653
	Agriculture	0.86	3.48	1.80	0.88	0.036	5.63	276.21	1.299	61.447	26.431
2010	Waterbody 2	377.95	0.18	1.31	0.12	0.01	1.03	0.58	598.406	0.010	0.032
	Other vegetation	0.24	0.87	2.17	1.05	1.24	6.96	28.90	0.249	68.261	1.938
	Built up	0.33	0.85	0.63	0.07	0.00	1.40	26.93	1.63	6.842	6.998

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Table 10 Forest density change matrix for the year 2010-2016

	Class	2016 (Area Sq.Km)				
		Non-Forest	Scrub	Open Forest	Moderately Dense Forest	Dense Forest
2010	**Non-Forest**	2004.71	22.35	46.88	110.22	38.90
	Scrub	36.42	6.97	13.81	14.00	1.48
	Open Forest	13.56	3.07	10.25	14.19	2.33
	Moderately Dense Forest	60.49	0.35	11.00	235.21	63.93
	Dense Forest	20.46	0.27	0.35	141.64	695.54

Area (sq. km)

From the above table 9 and 10, it is evident that for land use land cover, about 2058.94 sq.km of the area that was covered with classes Water body 1, Aqua Culture, Swamp, Mangrove 1 (*Avicennia alba* dominant), Mangrove 2 (Avicennia mixed) Scrubland, Agriculture, Water body 2, Other vegetation and Built up in 2010 remained the same in 2016. Around 941 sq.km of project area under the Open, Dense and Moderately Dense Forest in 2010 remained the same in 2016.

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Table 11 Land Use Land Cover Change matrix for 2016-2018

	LULC Class	2018 (Area Sq.Km)									
		Waterbody 1	Aqua Culture	Swamp	Mangrove1(*Avicennia alba* dominant)	Mangrove 2 (*Avicennia* mixed)	Scrubland	Agriculture	Waterbody 2	Other vegetation	Built up
2016	Waterbody 1	133.41	3.88	0.43	0.00	0.00	0.72	0.22	444.55	0.08	1.41
	Aqua Culture	4.25	35.05	2.19	0.00	0.00	0.79	0.60	0.39	0.79	6.25
	Swamp	1.39	0.45	89.17	9.78	37.09	23.35	1.08	3.80	3.09	1.49
	Mangrove1(*Avicennia alba* dominant)	0.02	0.00	19.59	199.18	146.84	22.34	0.22	0.69	1.81	0.22
	Mangrove 2 (*Avicennia* mixed)	0.00	0.00	24.58	231.77	609.66	18.38	0.00	0.04	0.23	1.01
	Scrubland	0.43	0.79	28.63	0.75	23.06	76.72	2.35	1.47	13.64	30.72
	Agriculture	0.57	1.08	9.77	0.92	0.84	3.58	288.21	6.44	18.52	1.46
	Waterbody 2	35.63	0.72	6.45	1.15	0.00	1.31	0.37	736.58	0.13	3.17
	Other vegetation	0.18	0.17	4.41	0.00	0.07	0.70	40.69	0.00	106.64	13.95
	Built up	0.27	0.46	0.23	0.00	0.00	0.38	20.292	0.04	1.95	0.00

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Table 12 Forest density change matrix for the year 2016-2018

	Class	2018 (Area Sq.km)				
		Non Forest	Scrub	Open Forest	Moderately Dense Forest	Dense Forest
	Non Forest	2024.89	22.20	23.82	50.96	13.69
	Scrub Forest	13.38	11.44	8.01	0.16	0.037
2016	Open Forest	32.19	9.12	30.19	10.70	0.095
	Moderately Dense Forest	75.49	3.06	32.01	273.97	130.74
	Dense Forest	14.39	0.11	2.25	25.68	759.75

Area (sq. km)

From the above table 11 and 12, it is evident that for land use land cover, about 2274.62 sq.km of the area that was covered with classes Water body 1, Aqua Culture, Swamp, Mangrove 1 (*Avicennia alba* dominant), Mangrove 2 (*Avicennia* mixed) Scrubland, Agriculture, Water body 2, Other vegetation and Built up in 2016 remained the same in 2018. Around 1063.91 sq.km of project area under the Open, Dense and Moderately Dense Forest in 2016 remained the same in 2018.

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Table 13 Land Use Land Cover Change matrix for 2018-2022

	LULC Classes	2022 (Area Sq.km)									
		Agriculture	Aqua Culture	Built Up	Mangrove 1 (Avicennia alba dominant)	Mangrove 2 (Avicennia mixed)	Other Vegetation	Scrub Land	Swamp	Waterbody 1	Waterbody 2
2018	Agriculture	**177.00**	3.15	17.69	85.76	61.97	9.21	9.63	6.49	0.41	5.53
	Aqua Culture	0.06	**18.91**	1.82	0.16	12.18	0.02	0.16	0.04	0.00	9.51
	Built Up	5.73	2.89	**4.08**	11.05	25.13	1.87	3.54	1.89	0.02	2.07
	Mangrove 1	26.67	0.36	1.07	**315.12**	32.54	21.44	56.76	47.44	0.01	0.71
	Mangrove 2	106.88	0.21	9.24	148.47	**403.73**	14.87	34.98	36.89	50.31	2.32
	Other Vegetation	32.63	0.49	5.25	45.90	4.41	**73.04**	4.16	3.15	0.21	1.86
	Scrubland	1.56	2.33	19.71	9.66	103.21	0.43	**0.21**	0.17	0.21	4.36
	Swamp	10.83	11.93	18.19	31.99	94.57	3.75	2.86	**2.42**	0.00	6.58
	Waterbody 1	0.02	8.72	0.92	0.08	5.51	0.00	0.01	0.00	**130.51**	29.47
	Waterbody 2	0.03	23.30	1.81	0.18	12.08	0.01	0.00	0.00	320.94	**736.47**

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Table 14 Forest density change matrix for the year 2018-2022

Classes		2022 (Area Sq.km)				
		Dense Forest	Moderately Dense Forest	Non Forest	Open Forest	Scrub
2018	Dense Forest	804.75	83.72	14.23	7.45	3.35
	Moderately Dense Forest	94.32	147.04	56.73	33.53	18.32
	Non Forest	154.56	145.82	1790.10	46.58	30.91
	Open Forest	20.31	25.32	35.51	8.27	5.27
	Scrub	3.75	6.78	26.35	3.00	2.14

From the above table 13 and 14, it is evident that for land use land cover, about 1861.49 sq.km of the area that was covered with classes Water body 1, Aqua Culture, Swamp, Mangrove 1 (*Avicennia alba* dominant), Mangrove 2 (Avicennia mixed) Scrubland, Agriculture, Water body 2, Other vegetation and Built up in 2018 remained the same in 2022. Around 960.06 sq.km of project area under the Open, Dense and Moderately Dense Forest in 2010 remained the same in 2016.

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Accuracy Assessment

The accuracy of spatial data has been defined by the United States Geological Survey (USGS) as: "The closeness of results of observations, computations, or estimates to the true values or the values accepted as being true" (USGS, 1990). The post classification accuracy assessment is an important part of the LULC classification and mapping which is used to analyse the precision of the classified maps. The classification accuracy quantifies the quality of maps produces and helps to evaluate the applicability of a map for a particular use. For an accurate interpretability and identification, the minimum accuracy of a classified map should not be less than 80 per cent. The techniques like Kappa coefficient, error matrix and indices-based techniques have already been used in several studies for the accuracy assessment of LULC maps produced.

The quality of LULC/forest maps derived from remote sensing data are often judged by evaluating the derived data against some reference (testing) data and interpreting the disagreement. The testing points prepared using Google Earth images on the Landsat satellite data were used for the accuracy assessment. We prepared an error matrix (also known as confusion matrix or contingency matrix). It is a cross tabulation of classified LULC, and actual land cover revealed by the testing sites results. We computed user's accuracy, producer's accuracy, overall accuracy, and kappa coefficients (Congalton, 1991). The user's accuracy is a measure of the reliability of the map and is represented by correct classified pixels in a class divided by the total number of pixels that were classified in that class. It informs the user how well the map represents what is really on the ground. The producer's accuracy measures how well a certain area has been classified and is computed by dividing the number of correct pixels in one class divided by the total number of pixels as derived from reference data. These two accuracies are represented using error of commission and error of omission, shown in table 12, 13, 14, 15 respectively. The overall accuracy is calculated by dividing the correctly classified pixels (sum of the values in the main diagonal) by the total number of pixels checked. The Kappa coefficient is a measure of overall agreement of a matrix. In contrast to the overall accuracy — the ratio of the sum of diagonal values to total number of cells counts in the matrix — the Kappa coefficient takes also non-diagonal elements into account (Rosenfield and Fitzpatrick, 1986).

The classification accuracy was evaluated. The classified images showed an Overall Accuracy of 83.07%, 82.05%, 85.97%, 83.50 and 89.27% in 2006, 2010, 2016, 2018 and 2022 respectively, with a kappa statistic of 0.780, 0.773, 0.995, 0.824, 0.797, and 0.86 respectively (Table 14, 15, 16, 17, 18 and 19)

Table 15 Accuracy Assessment with Error Matrix, 2006

Kappa Coefficient =0.780		
Overall Accuracy = 83.07%		
Class	**Commission (%)**	**Omission (%)**
Waterbody 1	2.2	0.31
Waterbody 2	2.13	7.73

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Kappa Coefficient =0.780		
Aquaculture	17.72	9.4
Swamp	60.45	15.69
Mangrove 1 (Avicennia alba Dominant)	23.58	16.42
Mangrove 2 (Avicennia Mixed)	31.68	45.19
Scrubland	27.59	45.44
Agriculture	0.28	6.46
Other Vegetation	88.39	22.58
Built up	71.72	3.45

Table 16 Accuracy Assessment with Error Matrix, 2010

Kappa Coefficient =0.773		
Overall Accuracy = 82.05%		
Class	Commission (%)	Omission (%)
Waterbody 1	5.31	4.3
Waterbody 2	6.08	7.79
Aquaculture	6.7	1.05
Swamp	79.69	28.68
Mangrove 1 (*Avicennia alba* Dominant)	17.14	24.79
Mangrove 2 (*Avicennia* Mixed)	24.33	23.98
Scrubland	26.33	44.76
Agriculture	0.48	13.61
Other Vegetation	78.52	14.39
Built up	95.28	33.78

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Table 17 Accuracy Assessment with Error Matrix, 2016

Kappa Coefficient =0.824		
Overall Accuracy = 85.97%		
Class	Commission (%)	Omission (%)
Waterbody 1	3.96	6.07
Waterbody 2	6.97	6.67
Aquaculture	18.24	2.11
Swamp	61.02	12.01
Mangrove 1 (*Avicennia alba* Dominant)	4.94	9.67
Mangrove 2 (*Avicennia* Mixed)	15.44	14.51
Scrubland	18.63	34.92
Agriculture	0.15	18.26
Other Vegetation	82.02	6.47
Built up	95.42	4.05

Table 18 Accuracy Assessment with Error Matrix, 2018

Kappa Coefficient =0.797		
Overall Accuracy = 83.50%		
Class	Commission (%)	Omission (%)
Waterbody 1	6.14	0.26
Waterbody 2	1.7	19.31
Aquaculture	24.2	12.7
Swamp	49.92	10.75
Mangrove 1 (Avicennia alba Dominant)	15.51	16.27
Mangrove 2 (Avicennia Mixed)	21.72	21.31
Scrubland	24.53	40.85

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Kappa Coefficient =0.797		
Agriculture	0.39	14.86
Other Vegetation	69.34	6.96
Built up	68.02	0

Table 19 Table 16 Accuracy Assessment with Error Matrix, 2022

Kappa Coefficient =0.867		
Overall Accuracy = 89.27%		
Class	Commission (%)	Omission (%)
Waterbody 1	4.96	6.07
Waterbody 2	5.97	6.67
Aquaculture	14.24	2.11
Swamp	47.02	11.01
Mangrove 1 (*Avicennia alba* Dominant)	4.94	8.67
Mangrove 2 (Avicennia Mixed)	13.44	14.51
Scrubland	18.63	23.92
Agriculture	4.15	18.26
Other Vegetation	63.02	6.47
Built up	61.42	3.05

Sampling Design and Biomass Estimation

For estimating the biomass, the project area has been stratified into different strata. Strata are basically the areas distinctly different from each other in forest types, density, and species; and as such they will have different amounts of carbon stored. To make strata as homogeneous as possible, a forest within the project area is divided into different layers or blocks.

Stratifying of the project area is done using stratified random sampling. After stratifying based on the canopy density the project area is divided into homogenous patches such as Very Dense Forest, Moderately Dense Forest, and Open Forest for calculation of biomass. For mapping the total number of samples plots we have randomly selected the plots of 0.1 Ha in the Project Area in consultation with the Forest Officials.

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The project area has been stratified into approximately homogenous units on the basis of forest canopy density. Satellite image has been classified into three different density-classes viz., "D1" with tree canopy density between 10 to 40%, "D2" with tree canopy density between 40 to 70%, and "D3" with tree canopy density of more than 70%.

Number of sample plots

To measure each and every tree within the each selected site is not only time consuming, but also practically not feasible. Pearson et al in 2005 has developed a statistical tool through which one can estimate the required number of sample plots to be laid in the project site that are statistically significant (Pearson et al, 2005). Thus, through this statistical tool, measuring only a fraction of trees from the total project area can provide true values of biomass of the entire project area. The number of estimated sample plots to be laid out in the selected site depends upon various factors such as size and number of stratums, basic carbon density and its standard deviation in the selected project area.

Pearson formula is used to calculate the number of sample plots that are required to be taken in the respective area. The formula for estimating the number of sample plots to be laid out at each pilot project site that will be statistically significant is mentioned below.

$$n = \frac{N \times t_{VAL}^2 \times \left(\sum_i w_i \times s_i \right)^2}{N \times E^2 + t_{VAL}^2 \times \sum_i w_i \times s_i^2}$$

Where,

E = Allowable error or the desired half-width of the confidence interval. Calculated by multiplying the mean carbon stock by the desired precision (that is, mean carbon stock x 0.1, for 10 per cent precision),

t = Sample statistic from the t-distribution table for 90% confidence level at infinite degree of freedom is 1.645 (A default value, also referred in tools for calculating sample plots in afforestation and reforestation CDM projects).

N = Number of sampling units for stratum (total area divided by plot area)

n = Number of sampling units in the population

s = Standard deviation of stratum

The calculation of number of sample plots is dependent on the Area of the forest type, and standard deviation. Where, standard deviation is calculated based on the pilot inventory. For Project Area the total number of sample plots is 102.

Table 20 Pearson Table

Strata	Area (Ha)	wi	si	si^2	wi*si	wi*si^2	ni
OpenForest	13250.25	0.07	0.9	0.81	0.07	0.06	11
Moderately Dense Forest	52497.27	0.29	0.8	0.64	0.23	0.18	38

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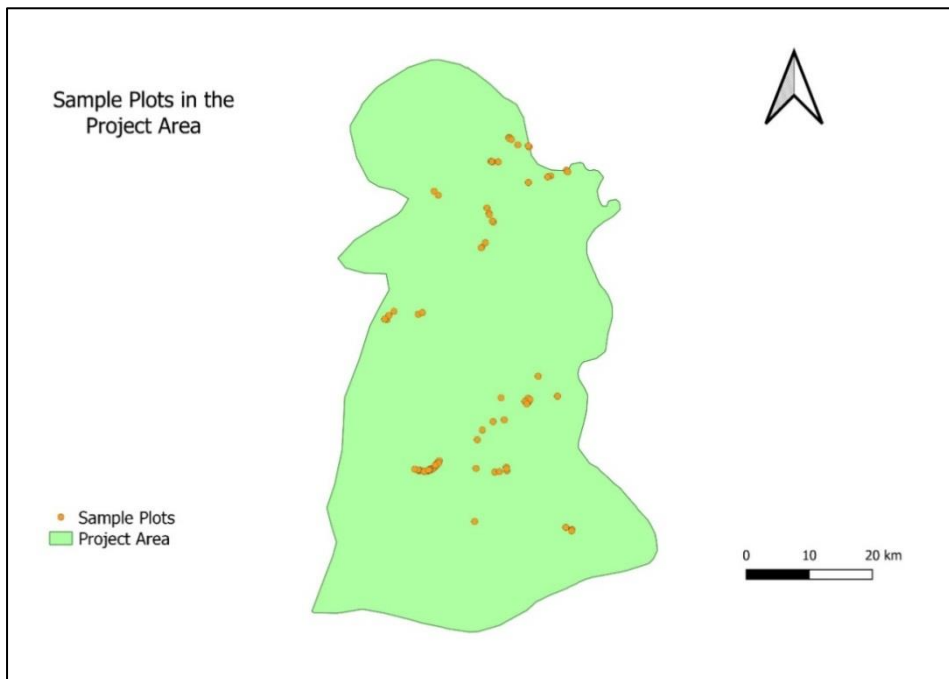| Strata	Area (Ha)	wi	si	si^2	wi*si	wi*si^2	ni
Dense Forest	116244	0.64	0.5	0.25	0.32	0.16	53
	181991.5				0.62	0.40	102

Geo-location of sampling sites

Figure 30 Location of sample plots in Project Area of Sundarban Tiger Reserve

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Laying out of Permanent Sample Plots

Stratified random samplings were done in the project area to lay out the sample plots. The geo coordinates of each sampled plot for all the sites were recorded with the help of Global Positioning System (GPS) tracking and digitized in the satellite imageries of each respective site. Square plot each of 31.62 m x 31.62 m size was laid on the project area as shown in Figure below.
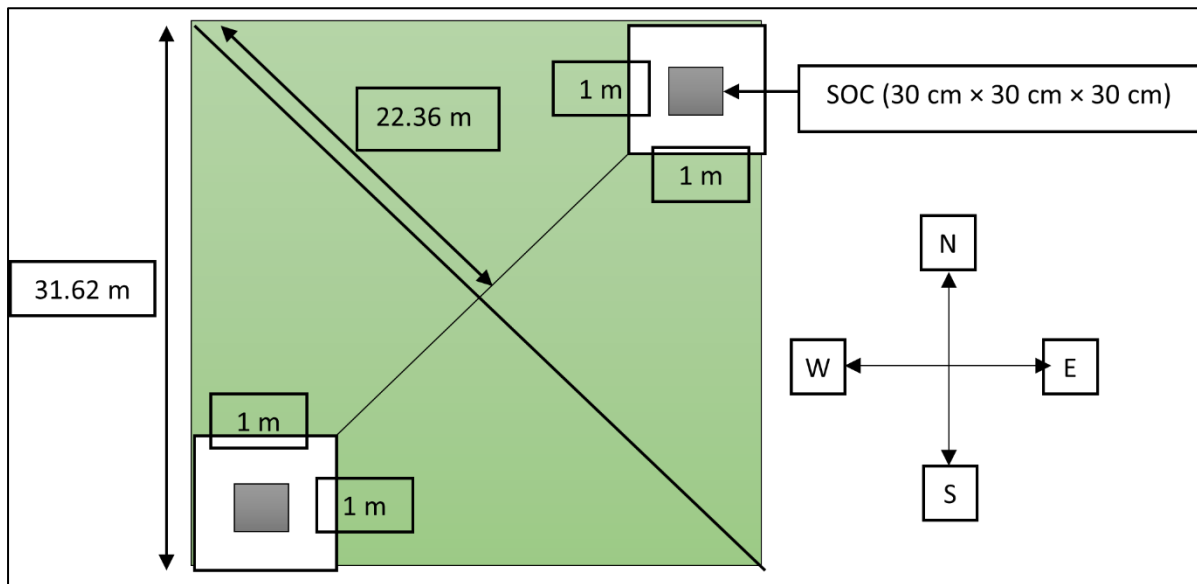

Figure 31 Permanent Sample Plot

Figure 32 Laying the Sample Plots

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Measurement of Above Ground Biomass, Below Ground Biomass

Measurement of Above Ground Biomass

Trees dominate the aboveground carbon pool in mangroves, and both their presence and condition are indicators of land-use change and ecological condition. It is essential to measure trees thoroughly and accurately.

Basic data that must be recorded for all individual mangrove trees in a plot include:

- Name of the Species
- Main stem diameter at breast height (DBH)
- Tree height
- Location and ID.

Non-destructive method was used for the estimation of above ground biomass. In this method, Diameter at Breast Height (DBH) and height of the trees falling within the sample plot was measured. Diameter at breast height (DBH) is the basic measurement standard for trees. This measurement is recorded for all trees.

The diameter of the tree's main stem is typically measured at 1.3 m above the ground. The different diameter measuring points in different situations are shown in Figure 33.

- If the tree is fairly straight with a tall trunk the DBH can be measured from the ground parallel to the trunk (Fig 33 A)
- If the tree is on a slope, always measure on the uphill side (Fig 33B)
- If the tree is leaning, DBH is taken according to the trees natural height parallel to the trunk (Fig 33 C)
- If the tree is forked at or below 1.3 m then measure just below the fork (Figure 33 D)
- If the fork is very close to the ground measure as two trees (Figure 33E)
- For trees with tall buttresses exceeding 1.3 m above ground level, stem diameter is usually measured directly above the buttress (Figure 33 F).
- For stilt rooted species (e.g., Rhizophora spp.), stem diameter is often measured starting above the highest stilt (Figure 33 G)

The measurements were then tabulated along sample plot number, botanical name of tree, local name of tree and remarks.
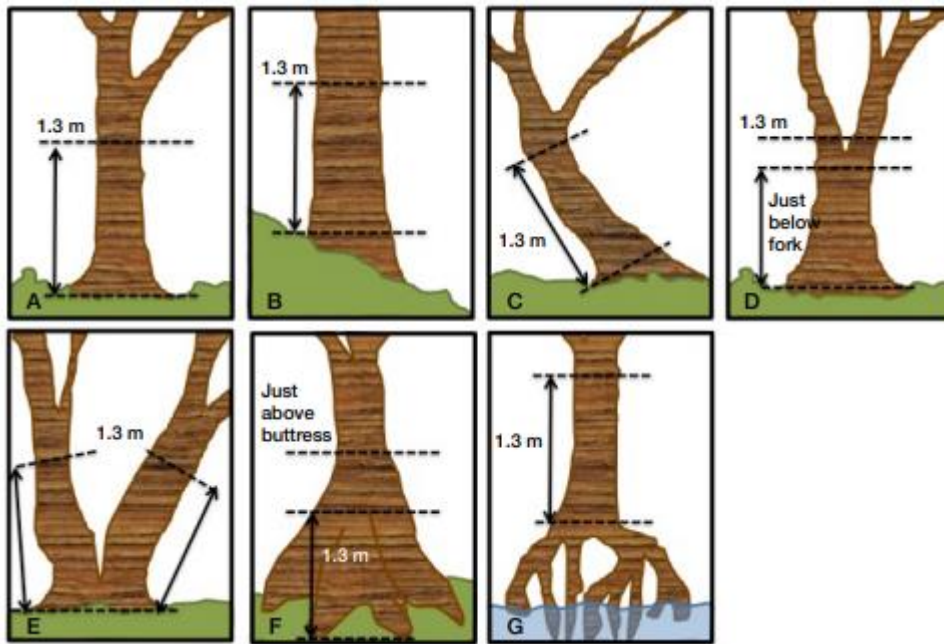
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Figure 33 Measurements of DBH of the tree

Figure 34 Collecting the Field Data

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Figure 35 Collection of data on the Field

Estimation of Below Ground Biomass

Below Ground Biomass can be estimated by using the value of 1.84 using a relationship AGB/BGB= 1.84[1] . Therefore, to estimate BGB as 54% of ABG

For Pneumatophores,

Pneumatophores of mangrove species of the genera *Avicennia, Brugueira, and Sonneratia* can be of significant structure and biomass. Microplots of size 50 x 50 cm2 were laid outside the permanent sample plots.

All pneumatophores (50–100 samples) within the plot were counted and collected.

Biomass for pneumatophores (kg) = Average dry mass of sampled pneumatophores * number of pneumatophores in the microplot.[2]

Measurement of Soil Organic Carbon

Soil organic carbon is determined through samples collected from the default depth as prescribed by FSI, 2017.

Soil samples were collected from two plots of size 1mx1m which were laid out within the main plot. At the centre of these two sub plots, a pit of 30cmx30cmx30cm was dug and composite sample of soil of 200gm were kept for organic carbon analysis.

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[1] Kamruzzaman, M., Ahmed, S., & Osawa, A. (2017). Biomass and net primary productivity of mangrove communities along the Oligohaline zone of Sundarbans, Bangladesh. *Forest Ecosystems*, *4*(1), 1-9.

[2] Alongi, D. M. (2018). *Blue carbon: Coastal sequestration for climate change mitigation*. *Field Sampling of Vegetative Carbon Pools in Coastal Ecosystems (pp.67-108)* Cham, Switzerland: Springer.

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All samples were placed into zipped pouches which are labelled appropriately. Samples of soil are analysed from the standard soil labs and used for calculation.

Deadwood biomass and leaf litter was not considered at the Sundarbans site. As this is a swampy area, the quantity of such biomass is negligible.

Calculation of Above Ground Biomass, Below Ground Biomass

The collected data from the field survey will be recorded in electronic database, which will be further analysed and using regression method biomass for the baseline year 2018 will be estimated.

The regression modelling to correlate the field-based biomass with predictor variable such as Normalised Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), Atmospherically Resistant Vegetation Index (ARVI) and to extrapolate the filed based biomass value in non-sampled areas would be done. Four regression functions such as linear, logarithmic, exponential, and power would be examined to find the best model between the observed and predictor variables. Correlation coefficients of best fit models thus obtained were used to model biomass for the entire region for Sundarban Project Area.

The database will also consist of information such as shape files of the plot areas, species found in the area and GPS coordinates of the plots.

For the calculations of biomass of every single tree species, above ground biomass equation i.e., $AGB = 0.251*WD*DBH^{2.46}$ [3] will be used.

Where,

AGB = Above Ground Biomass (in kg)

WD- wood density (gm/cm3)

DBH –Diameter at breast height (cm)

Below Ground Biomass would be measured using a relationship AGB/BGB= 1.84 as mentioned above.

Therefore, BGB = AGB /1.84

Where:

BGB = Below Ground Biomass and

AGB = Above Ground Biomass

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[3] Rahman, M. S., Donoghue, D. N., Bracken, L. J., & Mahmood, H. (2021). Biomass estimation in mangrove forests: a comparison of allometric models incorporating species and structural information. *Environmental Research Letters*, *16*(12), 124002.

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Table 21 List of Species found in the project area

Village	Species Found	Dominant species
Tibligheri	*Avicennia marina, Avicennia alba*	*Avicennia alba*
Pathopara	*Excoecaria agallocha, Avicennia marina, Avicennia alba*	*Avicennia marina*
Parashmani	*Ceriops decandra, Avicennia marin, Avicennia alba, Aegialitis rotundifolia, Aegiceras corniculatum, Acanthus ilicifolius, Sonneratia apetala*	*Avicennia alba*
Puinjali	*Avicennia officinalis, Avicennia alba*	*Avicennia officinalis*
Chimta	*Avicennia officinalis, Avicennia marina, Avicennia alba, Sonneratia apetala, Rhizophora apiculate*	*Avicennia officinalis*
Amtali	*Avicennia marina, Avicennia officinalis, Avicennia alba, Sonneratia apetala*	*Avicennia alba*
Jhingakhali	*Avicennia marina, Sonneratia apetala, Avicennia officinalis, Heritiera fomes, Excoecaria agallocha, Ceriops decandra, Xylocarpus granatum*	*Ceriops decandra*
Jhilla	*Excoecaria agallocha, Avicennia officinalis, Heritiera fomes, Bruguiera gymnorrhiza, Xylocarpus mekongensis, Xylocarpus granatum*	*Excoecaria agallocha*
Gosaba	*Avicennia marina, Avicennia alba, Acacia nilotica, Sonneratia apetala, Bruguiera gymnorrhiza, Ceriops decandra*	*Avicennia alba*
Baghmara	*Sonneratia apetala, Avicennia officinalis, Avicennia marin, Avicennia alba, Rhizophora apiculata*	*Avicennia alba*
Haldibari	*Avicennia marina, Ceriops decandra, Cerips tagal, Bruguiera parviflora, Sonneratia apetala, Excoecaria agallocha, Heritiera fomes, Xylocarpus granatum, Avicennia officinalis, Avicennia alba*	*Ceriops decandra*
Pirakhali	*Avicennia marin, Avicennia alba, Ceriops decandra, Avicennia officinalis, Ceriops tagal*	*Avicennia marin*
Chamta	*Sonneratia apetala, Ceriops decandra, Excoecaria agallocha, Aegiceras corniculatum, Avicennia marin, Avicennia officinalis, Avicennia alba, Xylocarpus granatum, Phoenix paludosa, Heritiera*	*Ceriops decandra*

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Village	Species Found	Dominant species
	fomes, Xylocarpus mekongensis, Aegialitis rotundifolia, Bruguiera gymnorrhiza	
Chandkhali	*Excoecaria agallocha, Xylocarpus mekongensis, Xylocarpus granatum, Rhizophora apiculata, Heritiera fomes, Ceriops tagal, Avicennia officinalis, Sonneratia apetala, Avicennia marin, Avicennia alba, Aegiceras corniculatum, Bruguiera gymnorrhiza, Bruguiera parviflora, Ceriops decandra, Sonneratia apetala*	*Rhizophora apiculata*

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Field Pictures

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