



Probable carbon credit – based market value of selected mangrove patches in Indian Sundarbans

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Abstract

Mangrove forests are highly productive with carbon storage potential almost equal or sometimes more than the terrestrial forest. The net primary production is about 12 tonnes dry wt. ha⁻¹ year⁻¹. This unique forest ecosystem accounts for 3% of carbon sequester by the World tropical forest, and 14% of carbon sequester in the World Ocean. Thus, mangrove forest may become a major player in the domain of carbon trading. The purpose of this study is to estimate the amount of carbon stored and its potential market value in few selected mangrove forests distributed in two sectors of Indian Sundarbans with contrasting variation in salinity. The western sector of Indian Sundarban Biosphere reserve (ISBR) is relatively low saline and promotes luxuriant growth of mangroves, whereas in the central sector exposed to high saline water, the mangroves exhibit stunted growth. Assessment of the monetary values of mangroves in context to mangrove carbon trading considering the Above Ground Biomass (AGB) and Above Ground Carbon (AGC) has been carried out in this research based on the market price of carbon in the voluntary market. The market valuation of the dominant mangrove tree species in the western sector is higher compared to the central sector of ISBR owing to higher AGB and AGC of mangroves in the former sector compared to the later.

Keywords: Mangrove forest, Carbon storage, Indian Sundarbans Biosphere reserve (ISBR), Carbon trading.

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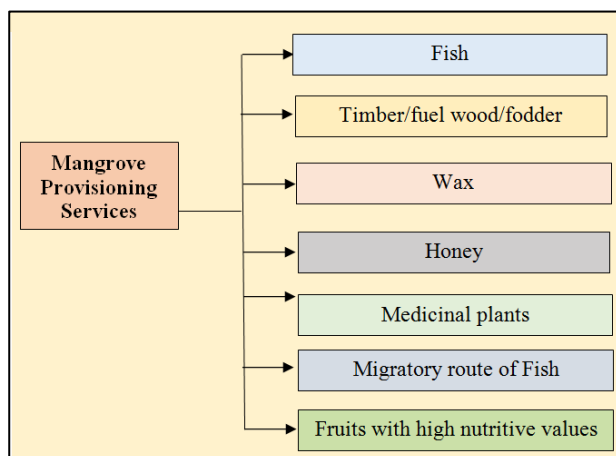
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1. Introduction

Mangrove forests are known for their usefulness to mankind. They are distributed at the land-sea interface and river mouth and provide several provisional services that directly benefit the coastal population and island dwellers (Figure 1).

Figure 1: Provisioning services of mangroves



Source: Authors.

Carbon sequestration by mangroves comes under the regulating services, and is now well known throughout the World and Indian Sundarban mangrove ecosystem is no exception to this rule [1-5]. The process of carbon sequestration is primarily governed by salinity [6-8].

The inhibitory role of salinity on the carbon storage potential of mangroves can be clearly visualized in Indian Sundarbans where two different contrasting salinity profiles are documented [9, 10]. The western Indian Sundarbans is relatively low saline as the estuaries in this sector receives the fresh water through the Hooghly-Bhagirathi River system connected to Gangotri Glacier of the Himalayan range [10]. The central sector, on the other hand, is exposed only to high saline water from the Bay of Bengal due to its disconnection with the Ganga - Bhagirathi River system because of heavy siltation since the 15th century [10, 11]. On this background we selected 10 stations distributed in the western and central sectors of Indian Sundarbans to assess the influence of salinity on the biomass and carbon storage potential of five dominant mangrove species namely *Sonneratia apetala*, *Avicennia marina*, *Avicennia alba*, *Avicennia officinalis*, and *Excoecaria agallocha*. Based on the carbon stock per unit area (herein hectare), an attempt has also been made to evaluate hectare -wise valuation of stored carbon through species – wise carbon dioxide - equivalent assessment.

2. Materials and Methods

2.1 Site selection and sampling

The stations highlighted in Table 1 and Fig. 1 are not uniform in nature preferably with respect to salinity. The River Hooghly adjacent to stations 1 to 5 supply fresh water to these stations making them low saline in nature. On the other hand, the River Matla (without any head on discharge leading to low level of dilution factor) provides salty water from the Bay of Bengal to stations 6 to 10 making them hypersaline. River Matla is fully deprived from fresh water supply due to heavy siltation and clogging of the Bidyadhari channel since the late 15th century. Because of this drastic variation in salinity between the two major estuaries, the floristic composition is also significantly different. Stations 1 to 5 are dominated by *Sonneratia apetala* and *Nipa fruticans*, whereas stations 6 to 10 are the rich habitat for *Avicennia* spp., *Excoecaria agallocha*, *Phoenix paludosa* etc.

Sampling of the dominant mangrove species (*Sonneratia apetala*, *Avicennia marina*, *Avicennia alba*, *Avicennia officinalis*, *Excoecaria agallocha*) were carried from all the selected stations during low tide period in March, 2023.

2.2 Above Ground Biomass (AGB) Estimation of Trees

Above Ground Biomass (AGB) of tree species refers to the sum of stem, branch and leaf biomass that are exposed above the soil. For each of the five dominant species in ISBR, 25 plots were selected in each station and AGB of each species was estimated using the standard formula as outlined by earlier researchers [12].

2.3 Above Ground Carbon (AGC) estimation of mangroves

Direct estimation of percent carbon in the AGB (referred to as AGC) was done by CHN analyser, after grinding the oven-dried stem, branches and leaves separately for each species. For this, a portion of fresh sample of stem, branch, and leaf from trees (of each species) was oven dried at 70⁰C, and ground to pass through a 0.5 mm screen (1.0 mm screen for leaves). The carbon content (in %) was finally analysed for each of the vegetative parts separately for the selected five species through a *Vario MACRO* elemental CHN analyser. Summation of carbon values of each of these vegetative parts (expressed in %) were considered as the stored carbon in the AGB of each species (referred to as AGC).



2.4 Financial aspect carbon stock for the selected stations

The carbon credit of mangroves is not a function of stored carbon, rather the value of stored carbon is transformed into carbon dioxide- equivalent (CO_2 - e) by a conversion factor of 3.67. In this study, we have measured the CO_2 - equivalent of dominant mangrove species for all the selected sites and a probable pricing was estimated considering the value proposed by authentic research works, Government Gazette, and organization.

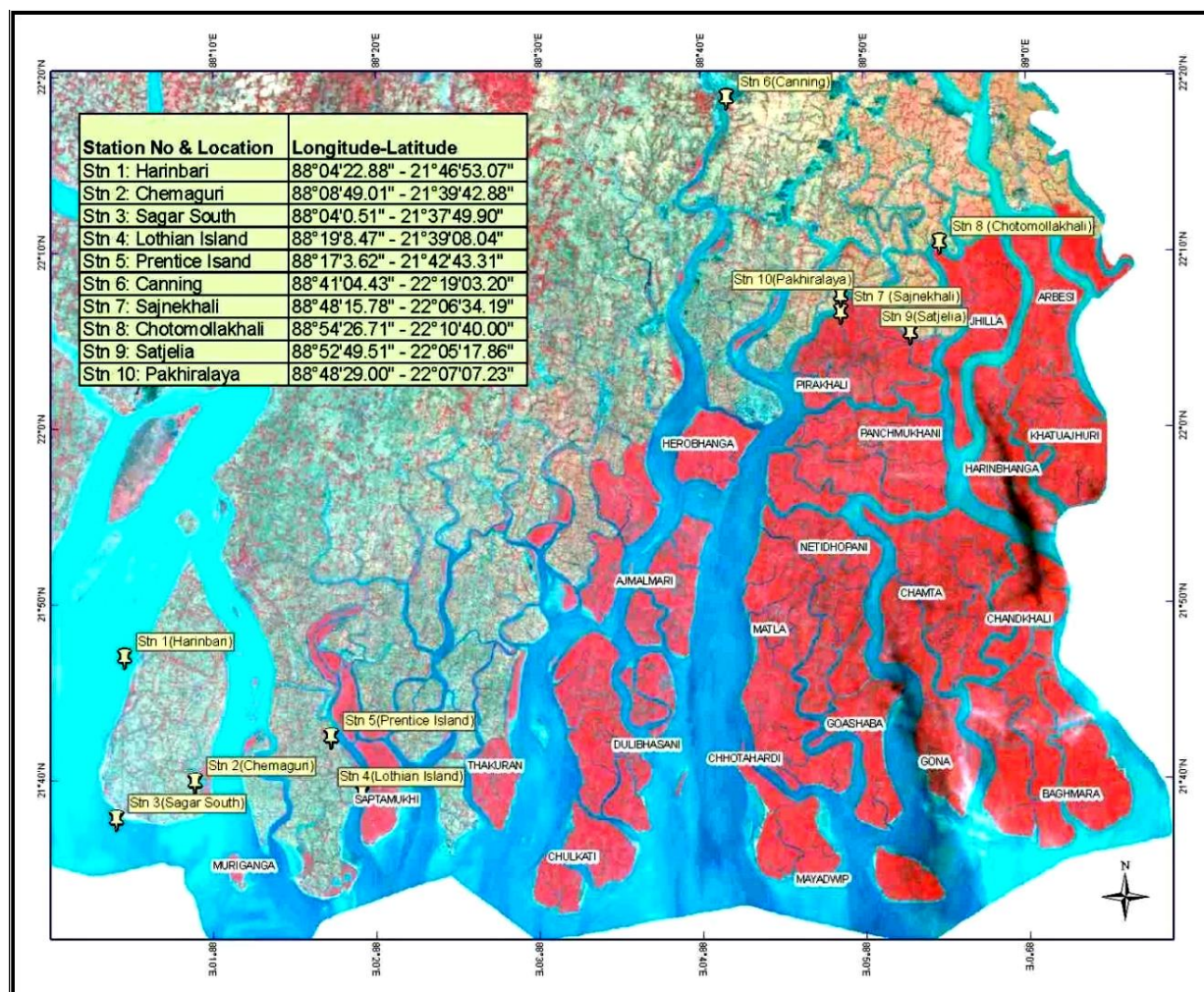
Table 1: Sampling stations with salient features

Study site	Coordinates	Site Description
Harinbari (Stn. 1)	88°04'22.88" E 21°46'53.07" N	Situated in the western region of Indian Sundarbans almost in the middle of the Sagar Island; receives the water of the Hugli River.
Chemaguri (Stn. 2)	88°08'49.01" E 21°39'42.88" N	Situated on the south-eastern side of Sagar Island and receives the water of the Mooriganga River.
Sagar South (Stn. 3)	88°04' 0.51" E 21°37'49.90" N	Situated on the south-western part of the Sagar Island at the confluence of the River Hugli and the Bay of Bengal. Anthropogenically stressed zone due to presence of passenger jetties, fishing activities and pilgrimage.
Lothian island (Stn. 4)	88°19'8.47" E 21°39'08.04" N	Situated east of Bakkhali island; a Wildlife sanctuary; faces the River Saptamukhi.
Prentice island (Stn. 5)	88°17'3.62" E 21°42'43.31" N	Situated north of Lothian Island; receives the water of the Saptamukhi River.
Canning (Stn. 6)	88°41'04.43" E 22°19'03.20" N	Situated in the central part of the Indian Sundarbans and faces the mighty River Matla, a tide-fed river. Due to presence of fish landing stations, passenger jetties and busy market, the area is anthropogenically stressed.
Sajnekhali (Stn. 7)	88°48'15.78" E 22°06'34.19" N	A Wildlife Sanctuary and a part of Sundarban Tiger Reserve; adjacent to River Bidhya and Gomor. Tourism pressure is extremely high in this station particularly during postmonsoon.
Chotomollakhali (Stn. 8)	88°54'26.71" E 22°10'40.00" N	Situated in the upper portion of Central Indian Sundarban adjacent to Jhila forest; receives the water of Rangabelia and Korankhali Rivers.
Satjelia (Stn. 9)	88°52'49.51" E 22°05'17.86" N	Situated adjacent to River Duttar in the upper region of Central Indian Sundarban facing western part of the Jhilla forest.
Pakhiralaya (Stn. 10)	88°48'29.00" E 22°07'07.23" N	Situated adjacent to River Gomor; opposite to Sajnekhali Wild Life Sanctuary.

Source: Authors.



Figure 2: Selected stations in Indian Sundarbans.



Source: Authors.






3. Results

The mean values of AGB and AGC of dominant mangrove tree species estimated from the patches selected from both the sectors of ISBR are presented in Table (2).

Table 2: Mean AGB and AGC (tonnes ha⁻¹) in the western and central Indian Sundarbans; the data of western sector represents the mean of stations 1 to 5, and the mean of stations 6 to 10 has been considered as the data of central sector of ISBR.

Sl. No.	Species	AGB (tonnes ha ⁻¹)		AGC (tonnes ha ⁻¹)	
		Western Sector	Central Sector	Western Sector	Central Sector



1		45.66	43.81	21.55 (47.2%)	19.85 (45.3%)
	Avicennia alba				
2		42.02	36.38	19.67 (46.8%)	16.77 (46.1%)
	Avicennia marina				
3		43.75	39.05	21.04 (48.1%)	17.14 (43.9%)
	Avicennia officinalis				
4		13.48	11.47	6.03 (44.7%)	5.07 (44.2%)
	Excoecaria agallocha				
5		33.88	13.19	16.64 (49.1%)	6.23 (47.2%)
	Sonneratia apetala ²				
Total Stored Carbon (tonnes ha ⁻¹)				84.93	65.06
Total CO ₂ -e (tonnes ha ⁻¹)				311.69	238.77

Note: The values within bracket represents the carbon (%). **Source:** Authors.

² (2023) Creative Commons (CC). https://en.wikipedia.org/wiki/File:Mangrove_knees_Yap.jpg



One of the important road maps to reduce CO₂ emissions from point and non-point sources is setting a price for carbon (more precisely CO₂ -e) through trading schemes or by implementing carbon taxes. The Ministry of Environment, Forest and Climate Change, Government of India issued a notification on 12th October 2023 in which a Green Credit programme has been launched at national level to leverage a competitive market-based approach for Green Credit for incentivizing environmental actions of various stakeholders.

Under Green Credit programme, eight activities have been referred (Table 3).

Based on the ability of trees to remove CO₂ from the atmosphere through the process of photosynthesis, the costs associated with mangroves of both the sectors of Sundarbans are presented in Table 4. It is to be noted in this context that the present initiative has been taken by the authors as per the national guide line on “Mangrove Conservation and Restoration” published by the Government of India on 12th October, 2023 as a component of “Green Credit” initiative.

Table 3: Major Activities under Green Credit of Government of India.

S. No	Activity	Details
1	Tree Plantation	Promotion of increasing green cover across the country.
2	Water Management	Promotion of water conservation, water harvesting and water use efficiency or water savings, including treatment and reuse of waste water.
3	Sustainable Agriculture	Promotion of natural and regenerative agricultural practices and land restoration of improve productivity, soil health and nutritional value of food produced.
4	Waste Management	Promotion of circularity, sustainable and improved practices for waste management, including collection, segregation, and environmentally sound management.
5	Air Pollution Reduction	Promotion of reducing air pollution and other pollution abatement activities.
6	Mangrove Conservation and Restoration	Promotion of conservation and restoration of mangroves.
7	Eco-mark label development	Encouragement of manufacturers to obtain eco mark label for their goods and services.
8	Sustainable Building and Infrastructure	Encouragement of the construction of sustainable buildings and other infrastructure using environment friendly technologies and materials.

Source: Authors.

4. Discussions

Mangroves are coastal forest ecosystems occurring in unconsolidated substrata in sheltered intertidal zones of tropical, subtropical, and warm temperate regions of the planet Earth. They are globally recognized for being highly important in terms of ecological, economic, social, and cultural functions due to the variety of goods and services they provide, reaching an estimated annual economic value of more than US\$ 900000/km² [13]. The biomass and productivity of forests have been studied mainly in terms of wood production, forest conservation and ecosystem management [14,15,16,17,18,19]. The goods and services provided by mangroves include, among others, the protection of coastline from the storms, tidal surges, wave actions and the maintenance of fisheries and biodiversity in coastal and estuarine water masses [20,21,22]. The contemporary understanding of the

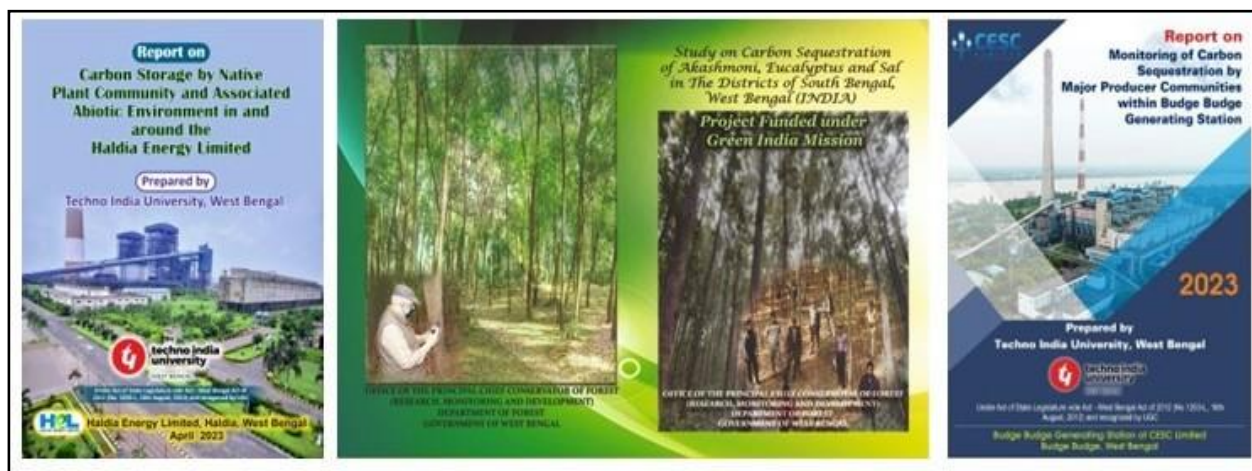
global warming phenomenon, however, has generated interest in the carbon-stocking ability of trees. In recent years, carbon storage and sequestration have been recognized as one of the most important environmental services provided by this ecosystem [1, 2, 10, 23-26]. The carbon sequestration in this unique producer community is a function of biomass production capacity, which in turn depends upon interaction between edaphic, climate, and topographic factors of an area. Hence, results obtained at one place may not be applicable to another [9]. Therefore, region-based potential of different land types needs to be worked out. In the present study, mean values of AGB and AGC data have been presented for the two sectors of ISBR, which are significantly different in terms of salinity, that forms the ecological basis of price variation of mangrove trees in accordance with the “Green Credit” initiative of the Government of



India (Table 4). The pricing can also vary by project type, size, location, and other determining factors, preferably the degree of threats to the producer community and surrounding habitats. India's lucrative carbon market is worth over \$1.2 billion. It has possibility to grow as the crisis of climate change becomes more urgent and companies strive to attain net-zero emission goals. In this context, it is to be noted that already few

Government departments (like West Bengal Forest Department), and Private Sectors (like Haldia Energy Limited and Budge Budge Generating Station of CESC Limited) have initiated the assessment of stored carbon in the producer communities with the aim to evaluate the carbon storage potential of the species (Figure 3), which is in alignment with the “Green Credit” mission of the Government of India.

Figure 3: Reports on carbon sequestration by tree species.



Source: Authors.

Table 4: Costs associated with carbon dioxide removal by mangrove trees in two sectors of ISBR (only 5 stations were selected in each sector)

Type	Western Sector	Central Sector
	Cost in INR	Cost in INR
Natural trees (\$10-\$50/metric tonne)	$311.69 \times \$10 \times 83.39 = \text{INR } 259918.29$ to $311.69 \times \$50 \times 83.39 = \text{INR } 1299591.46$ Source: [27, 28]	$238.77 \times \$10 \times 83.39 = \text{INR } 199110.30$ to $238.77 \times \$50 \times 83.39 = \text{INR } 995551.52$
Artificial trees (\$100-\$600/metric tonne)	$311.69 \times \$100 \times 83.39 = \text{INR } 2599182.91$ to $311.69 \times \$600 \times 83.39 = \text{INR } 15595097.46$ Source: [28]	$238.77 \times \$100 \times 83.39 = \text{INR } 1991103.03$ to $238.77 \times \$600 \times 83.39 = \text{INR } 11946618.18$
Carbon Credit (\$50-\$200 for forest carbon activities)	$311.69 \times \$50 \times 83.39 = \text{INR } 1299591.46$ to $311.69 \times \$200 \times 83.39 = \text{INR } 5198365.82$ Source: [29]	$238.77 \times \$50 \times 83.39 = \text{INR } 995551.52$ to $238.77 \times \$200 \times 83.39 = \text{INR } 3982206.06$
India's social cost of Carbon emission	$311.69 \times \$86 \times 83.39 = \text{INR } 2235297.30$ Source: [30]	$238.77 \times \$86 \times 83.39 = \text{INR } 1712348.61$
Carbon Credit through Improved Forest Management	$311.69 \times \$2 \times 83.39 = \text{INR } 51983.66$ to $311.69 \times \$17.5 \times 83.39 = \text{INR } 454857.00$ Source: [31, 32]	$238.77 \times \$2 \times 83.39 = \text{INR } 39822.06$ to $238.77 \times \$17.5 \times 83.39 = \text{INR } 348443.03$

Note: Conversion of US\$ to INR has been done based on the conversion rate on 13.12.2023 1\$ = INR 83.39.

Source: Authors.



Based on the values stated in Table (4), it can be stated that promotion, conservation, and restoration of mangrove species involving the island dwellers of ISBR can earn incentives for the local people, which can be re-utilized to replicate the green initiatives in several islands of ISBR including Sundarban Tiger Reserve (STR), where hyper salinity has posed ecological threat to the endemic Blue Carbon community.

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