



The Role Of Mangrove Plantations In Enhancing Coastal Resilience In The Sundarbans: A Case Study Of Chorgheri Village Of Satjalia Island, South 24 Parganas, West Bengal.

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Abstract:

The Sundarbans, located in the deltaic region of West Bengal, India, is a unique ecological zone and the mangrove forest in this region act as a natural defense against cyclonic hazards emanating from the Bay of Bengal. Mangrove forests in this region serve as a vital buffer. They help in dissipating wave energy, mitigating storm surges, and reducing coastal erosion. Mangroves also can act as a carbon sink by capturing and storing atmospheric carbon di oxide in the coastal mudflats. Thus carbon stored in coastal ecosystems is known as blue carbon. Due to their high carbon sequestration capabilities, mangroves are considered an important element to mitigate climate change. This study focuses on Chorgheri settlement of Satjalia Island, a cyclone-prone region within the Sundarbans, to assess the role of mangrove plantations in environmental protection and community resilience. Using field surveys, interviews with local residents, and secondary data, the study highlights the significant contributions of mangrove restoration projects in reducing the impacts of cyclones such as Aila (2009), Amphan (2020), and Yaas (2021). The findings demonstrate that mangrove plantations not only mitigate physical damage but also enhance biodiversity and provide economic benefits through improved livelihoods. The present study focuses on the participatory approaches of the locals and also on the restoration of sustainable practices to harness the full potential of mangroves to reduce disaster risks in the coastal regions.

Keywords: Sundarbans of West Bengal, plantation of mangroves, storm mitigation, environmental protection, Carbon sink, Chorgheri Village of Satjalia island, disaster resilience, carbon sequestration, climate change, coastal ecosystems.

Introduction:

The Sundarbans, spanning the deltaic regions of India and Bangladesh, is the world's largest contiguous mangrove forest and a UNESCO World Heritage Site. This unique ecosystem is renowned for its rich biodiversity, including iconic species such as the Royal Bengal Tiger, and its critical role in providing ecological services. However, the Sundarbans is also one of the most vulnerable regions to climate change and extreme weather events, particularly tropical cyclones originating from the Bay of Bengal. Over the past few decades, the frequency and intensity of cyclonic storms have increased significantly due to rising sea surface temperatures and changing climate patterns.

Cyclonic hazards, such as Cyclone Aila (May 2009), Fani (May 2019), Bulbul (November 2019), Amphan (May 2020), and Yaas (May 2021), Sitrang (October 2022) have caused widespread devastation in the Indian Sundarbans, including loss of lives, destruction of property, saline water intrusion, and degradation of farmlands. The mangrove forests, however, have proven to be a vital natural defense system against these disasters. Acting as a green shield, mangroves reduce the intensity of storm surges as a barrier, absorb wave energy, minimize coastal erosion and protect both human settlements and the fragile coastal environment. Despite this, mangroves can also play the role of carbon sink by absorbing and storing more carbon di oxide in the coastal mudflats from the environment than they release in the atmosphere. These stored carbons are also known as blue carbon which in turn slows down the process of climate change.



Plate: 1 Mangroves and their roots (Photo taken by the author during field survey on January, 2025)

Chargheri settlement, located on the southeastern part of Satjalia Island in the Indian Sundarbans, represents a microcosm of the region's struggles and resilience. This small village is highly vulnerable to cyclonic hazards due to its geographical location and socio-economic challenges. However, the role of community-driven mangrove restoration efforts in enhancing resilience has gained significant attention in recent years. The village provides a unique case study to understand how mangrove plantations contribute to environmental protection, disaster risk reduction, and livelihood support. Through an in-depth analysis of Chargheri Village, this study underscores the critical importance of mangrove plantations as a cost-effective and sustainable solution for addressing the dual challenges of environmental protection and climate adaptation in the Sundarbans.

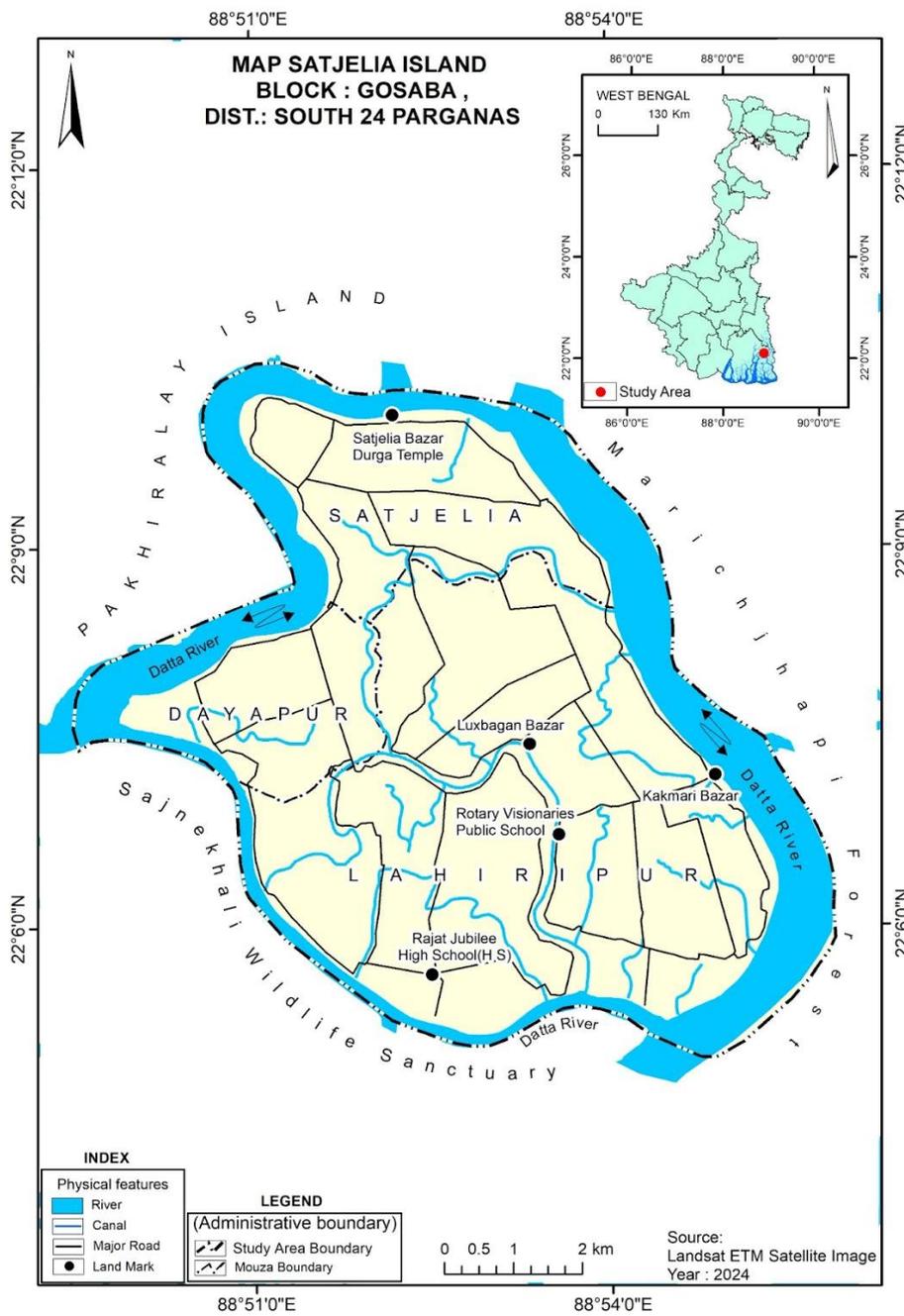


Fig. 3

Source: Landsat ETM Satellite Image, 2024

Earthen embankments along Datta river have been constructed after the Aila cyclone. In some portions bricks and cement have also been used to construct the embankment. The embankment also known as Aila embankment has a length of 4 kilometres and a width of 10 metres along the eastern part of Chargheri settlement.



Plate: 2

Brick and cement embankment at Chargheri (Photo taken by author during field survey)



Plate: 3

Author on the embankment during field survey (January, 2025)



Plate: 4

Earthen embankment from Kakmari ferry ghat to Lahiripur (Photo taken by author during field survey)





Plate: 5

Previous earthen embankment from Kakmari ferry ghat to Lahiripur destructed in 2009 Aila cyclone (Photo taken by author during field survey)

From Kakmari ferry ghat to Lahiripur, the embankment is 7 kilometres long and 5.5 metres broad.

All these embankments were constructed after the complete or partial destruction of the previous embankments during Aila cyclone in 2009.

Objectives of the Study:

The primary objective of this study is to assess the role of mangrove plantations in protecting the Sundarbans, particularly in the Chargheri village on Satjalia Island, from cyclonic hazards while contributing to environmental sustainability. The study aims to evaluate the effectiveness of mangrove restoration in mitigating storm surges, preventing coastal erosion, and enhancing climate resilience. The specific objectives include:

- to assess how mangrove forests act as natural barriers against storm surges, strong winds, and flooding in cyclone-prone areas like Chargheri village,
- to examine the consequences of past cyclones (e.g., Cyclone Amphan, Cyclone Aila) to understand how mangrove cover influenced damage mitigation,
- to investigate how mangrove forests contribute to biodiversity conservation, carbon sequestration, and water quality improvement,
- to examine the role of mangroves in preventing soil erosion and maintaining coastal stability,
- to assess the socio-economic benefits of mangrove conservation for local communities,
- to analyze how mangrove restoration supports livelihoods through sustainable fishing, honey collection, and ecotourism,
- to identify community-driven conservation initiatives and their impact on local economies,
- to suggest strategies for integrating mangrove conservation into coastal zone management policies,
- to advocate for stronger financial incentives, and community participation in mangrove conservation,

By addressing these objectives, the study aims to highlight the critical importance of mangrove ecosystems in disaster risk reduction and environmental sustainability while providing actionable recommendations for policymakers, conservationists, and local communities.

Methodology:

This study employs a mixed-methods approach to analyze the role of mangrove plantations in mitigating cyclonic hazards and protecting the environment in Chargheri Village on Satjalia Island. The methodology involves field surveys, interviews of the local people, geospatial analysis and a review of secondary data to comprehensively assess the ecological and socio-economic impacts of mangrove plantations. Evidence of cyclone impacts, such as damaged infrastructure, eroded shorelines, and inundated agricultural lands, was recorded to analyze the protective role of mangroves. Interviews were conducted with local villagers, community leaders, and representatives from NGOs involved in mangrove restoration projects. Satellite imagery and GIS tools were used to analyze changes in mangrove cover over time. Government reports, NGO publications, media reports and academic studies on mangrove restoration projects in the Sundarbans were reviewed. Cyclone records and disaster impact reports were analyzed to correlate the presence of mangroves with reduced cyclone damage.

Role of Mangroves:

Mangroves are vital to coastal ecosystems and communities. They protect coastlines, provide habitats for marine life, and help regulate the climate. They act as a buffer between land and sea, reducing the damage from waves, storms, and flooding. They also help to stabilize soils, which reduces the risk of erosion

Mangrove forests are nature's most effective coastal defense systems, particularly in regions like the Sundarbans, which are prone to extreme weather events such as cyclones. This section elaborates on how mangroves act as natural barriers against cyclonic hazards, supported by evidence and specific examples from Chargheri Village.

Mangroves reduce the energy of waves and storm surges by acting as a buffer zone between the ocean and inland areas. The dense network of roots and canopies traps sediment, slows water flow, and absorbs wave energy, which significantly reduces the force of storm surges. Studies have shown that a 100-meter-wide mangrove belt can reduce wave energy by up to 50%, and wider belts can mitigate even stronger surges.

In Chargheri Village, this role has been particularly evident during cyclones like Amphan (2020) and Yaas (2021). Villagers observed that areas protected by mangroves suffered less damage compared to those without such cover. During Amphan, homes and embankments shielded by mangroves experienced reduced inundation and erosion, highlighting the importance of these natural barriers.

Mangroves play a crucial role in stabilizing shorelines by trapping sediment with their extensive root systems. This process prevents coastal erosion, a common issue exacerbated by strong winds, tidal waves, and storm surges during cyclones.

Chargheri Village has long faced the problem of shoreline erosion, but mangrove plantation efforts in recent years have contributed to mitigating this issue. The roots of species like *Avicennia* and *Rhizophora* have been particularly effective in holding sediment in place, thereby protecting agricultural land and settlements from being washed away.

Mangroves, with their dense canopies and tall structures, act as windbreakers, reducing wind speeds during cyclonic storms. The friction created by the leaves, branches, and trunks slows down the wind, which in turn reduces the damage to infrastructure and crops.

During Cyclone Aila (2009), the presence of mangroves around Chargheri Village was reported to have mitigated wind damage to homes and agricultural fields. Local residents noted that areas without mangroves faced more severe destruction, emphasizing the protective function of these forests.

By protecting inland areas from salinity intrusion caused by storm surges, mangroves help preserve freshwater resources and agricultural land. Salinity intrusion can render soil infertile and contaminate drinking water sources, leading to long-term socio-economic challenges.

In Chargheri Village, mangroves have been instrumental in protecting paddy fields and freshwater ponds from salinization during cyclones. Additionally, the ecosystem services provided by mangroves, such as fisheries and honey production, have supported the livelihoods of local communities, even in the aftermath of cyclonic disasters.



Plate: 6

Differential heights of mangrove plantation in various years after the 2009 Aila cyclone (Photo taken by author during field survey)

After the Aila cyclone in 2009, local NGO has organised the village women to collect mangrove seeds blobbing in the high tide river water and collecting them to prepare mangrove saplings. These saplings are further planted along the river banks to protect storm surge during future cyclones.

Mangroves provide critical habitats for a wide range of flora and fauna, many of which contribute to the ecological balance of the region. The biodiversity supported by mangroves also enhances ecosystem resilience, enabling faster recovery after cyclonic events.

In the Sundarbans, the presence of mangroves has allowed species like mud crabs, prawns, and fish to thrive, offering a stable source of income for communities like those in Chargheri Village. During cyclones, these habitats serve as refuges for wildlife, minimizing biodiversity loss.



Plate: 7

Mud crabs found on the low tidal mudflats (Photo taken by author during field survey)

Case Evidence from Chargheri Village:

The role of mangroves in cyclone mitigation has been particularly evident in Chargheri Village. Field observations and interviews revealed the following key points:

- Villages with dense mangrove cover experienced significantly less damage to homes and embankments during Cyclone Amphan compared to neighboring areas without mangroves.
- Mangrove plantation initiatives led by local communities and NGOs have strengthened the village's resilience against cyclonic hazards.
- Fishermen and honey collectors reported that the health of mangrove ecosystems directly correlates with their livelihoods, reinforcing the need for conservation.

Mangroves are indispensable for mitigating the impacts of cyclonic hazards in the Sundarbans. The evidence from Chargheri Village underscores their effectiveness in reducing wave energy, preventing erosion, slowing wind speeds, and protecting inland ecosystems. As cyclones become more frequent and intense due to climate change, the role of mangroves in safeguarding vulnerable communities like Chargheri will only become more critical.

Table:1. Specimen of Mangroves used for plantation.

Sl. No.	Species	Scientific Name	Local Name	Root Type	Carbon Sequestration Ability	Location
1.	Goran	Ceriopsdecandra	Goran	Pneumatophores	More	Upland Hard Silty Soil
2.	Bain	Avicennia alba,marina	Bain	Pneumatophores	Maximum	Soft Silty Soil
3.	Garjon	Rhizophora mucronata	Garjon	Stilt Roots	More	Upland Hard Silty Soil
4.	Kankra	Bruguieragymnorhiza	Kankra	Pneumatophores	More	Upland Hard Silty Soil
5.	Dhunndul	Xylocarpus granatum	Dhudul	Pneumatophores	More	Upland Hard Silty Soil
6.	Panshur	Xylocarpusmekongensis	Panshur	Pneumatophores	More	Upland Hard Silty Soil
7.	Kaora	Sonneratia apetala	Kaora	Pneumatophores	Maximum	Soft Silty Soil

8.	Gaoya	Excoecariaagalocha	Gaoya	Spreading Root	More	Upland Hard Silty Soil
9.	Sundari	Heritiera fomes	Sundari	Pneumatophores	More	Upland Hard Silty Soil
10.	Sea Grass	Porteresiacoarctata	Sea Grass	Rhizomes	Maximum	Soft Silty Soil
11.	Hargoja	Acanthus ilicifolius	Hargoja	Stilt Roots	More	Upland Hard Silty Soil
12.	Tora	Aegialitis rotundifolia	Tora	Tap Root	More	Upland Hard Silty Soil
13.	Khalshi	Aegiceras corniculatum	Khalshi	Pneumatophores	More	Upland Hard Silty Soil

Source: Purbasha Eco-helpline Society, 2025

Table:2. Plantation of Mangrove species along the River Banks, 2009-2021.

River Bank	Mangrove Plantations and No. of Saplings Planted	Height of saplings	Mortality Rate	Siltation Rate
Chargheri	2009 August 3,00,000	0.50-0.61 m	30%	0.10-0.15 (December)
Chargheri	2017 1,00,000	10.97-12.19 and 0.52-0.62 m	35%	0.70-0.80 (December)
Chargheri Kakmari	2019 1,00,000	6.09 m- 7.62 m and 0.48-0.60 m	30%	0.30-0.45 (December)
Kakmari Kumirmari Sonagaon	2021 60,000	3.05-3.66 m and 0.55-0.60 m	38%	0.40-0.42 (December)

Source: Purbasha Eco-helpline Society, 2025

Table:3. Yearwise plantation of Mangrove saplings.

Villages along the River Bank Area	Year	No. of Mangrove saplings Planted	No. of persons involved in plantation	No. of mangrove seeds collected
Chergheri	2009	3,00,000	220	4,30,000
Chergheri	2010	Protection Pyramid	220	50,000
Chergheri	2011	Protection Pyramid	50	30,000
Chergheri	2012	Protection Pyramid	50	30,000
Chergheri	2013	Protection Pyramid	50	20,000
Chergheri	2014	Protection Pyramid	50	20,000
Chergheri	2015	Protection Pyramid	50	10,000
Chergheri	2016	Protection Pyramid	50	10,000
Chergheri	2017	1,00,000	50	75,000
Chergheri	2018	50,000 replanted	50	80,000
Chergheri	2019	1,00,000	50	60,000
Chergheri, Kakmari, Kumirmari, Sonagaon	2020	42,000	250	90,000
Chergheri, Kakmari, Kumirmari, Sonagaon	2021	60,000	280	90,000
Chergheri, Kakmari, Kumirmari, Sonagaon	2022	70,000	350	1,10,000
Chergheri, Kakmari, Kumirmari, Sonagaon	2023	70,000	380	1,20,000
Chergheri, Kakmari, Kumirmari, Sonagaon	2024	219000	500	1,30,000

Source: Purbasha Eco-helpline Society, 2025.

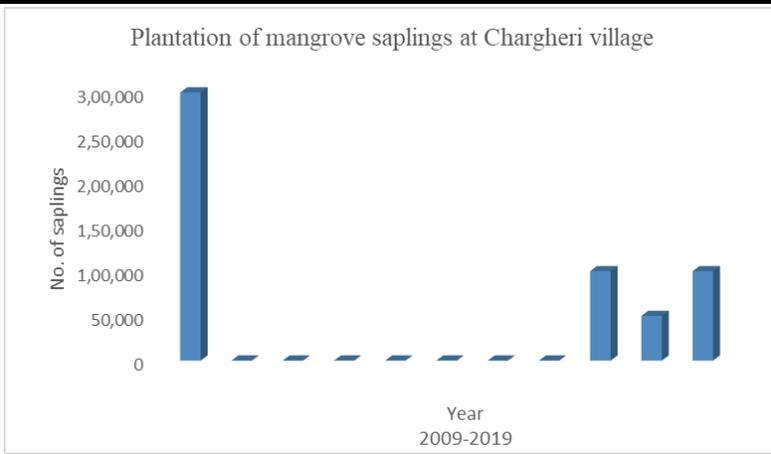


Fig. 4

Source: Table 3

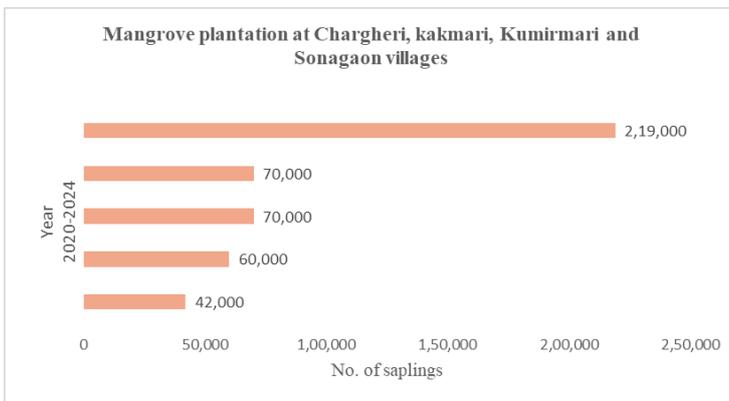


Fig. 5

Source: Table 3



Plate: 8

Measuring height of mangrove tree planted after Aila cyclone in May 2009 (Photo taken by author during field survey)



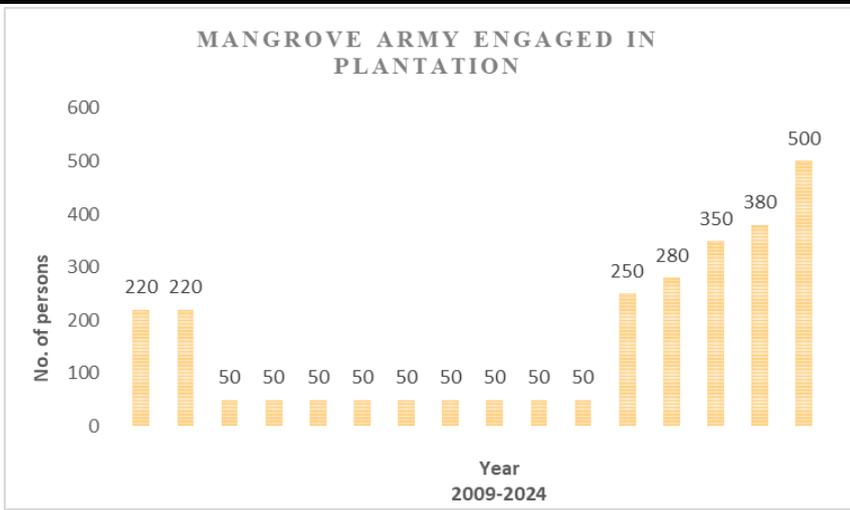


Fig. 6

Source: Table 3



Fig. 7

Source: Table 3



Plate: 9

Women belonging to Mangrove Army with the mangrove saplings in front of their nursery (Photo taken by author during field survey)



Plate: 10

Author planting mangrove saplings in Chargheri village along the coastal line (Photo taken by author during field survey)

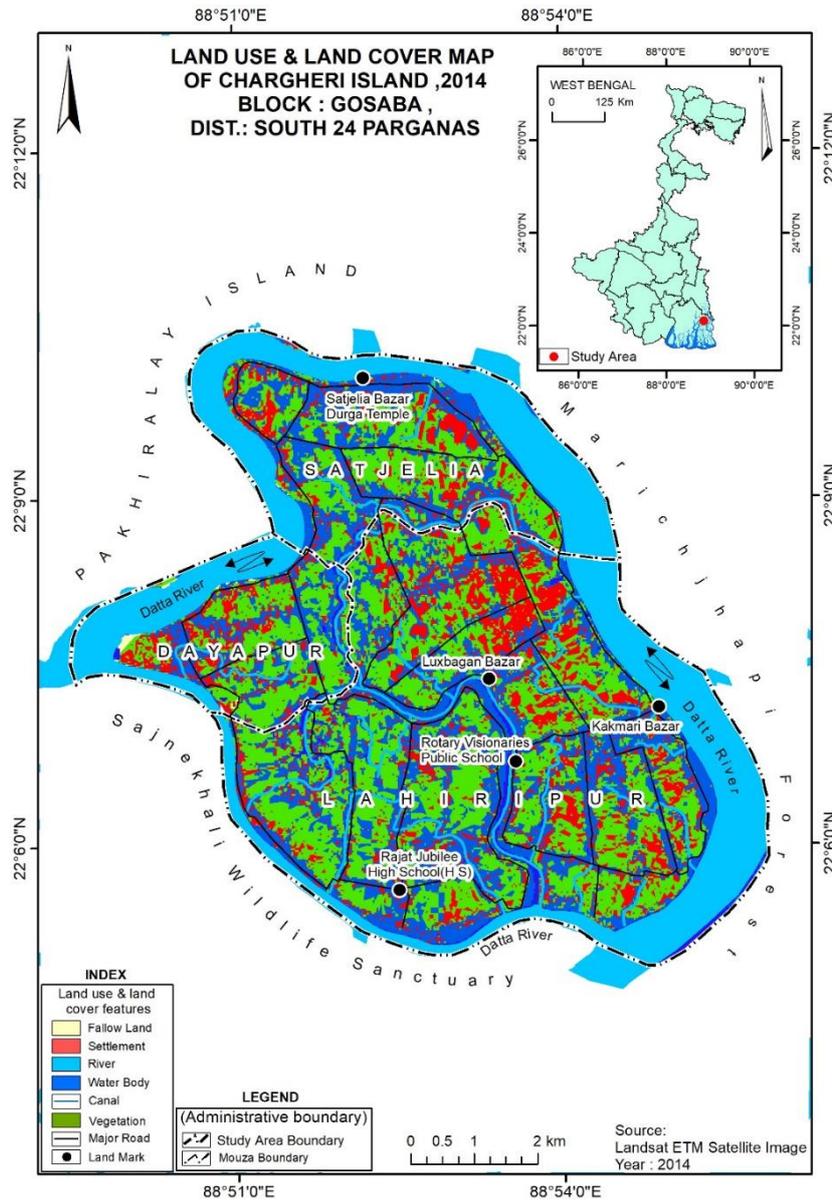


Fig. 8

Source: Landsat ETM Satellite Image, 2014

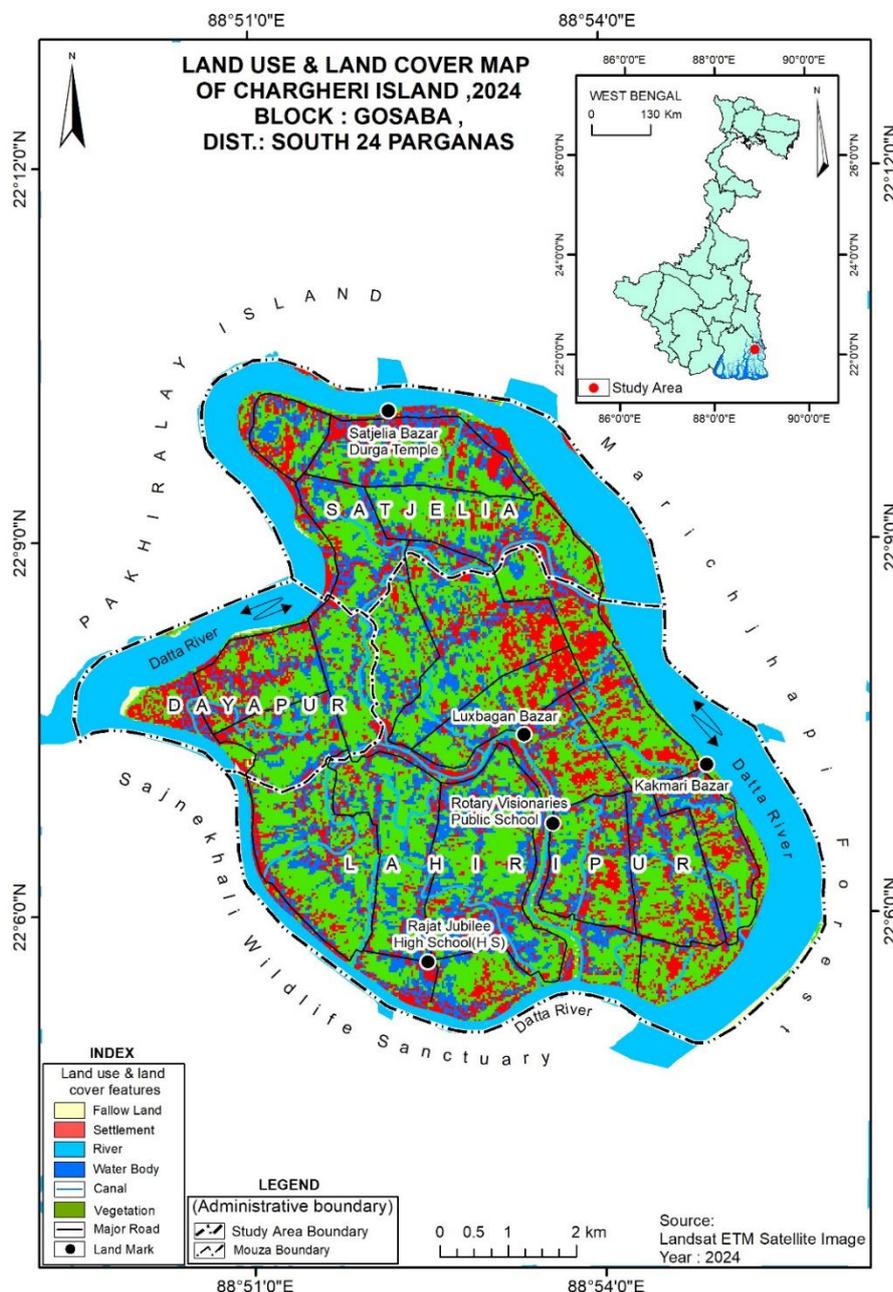


Fig. 9

Source: Landsat ETM Satellite Image, 2024.

Satjelia Island, the last habitable village on the southeastern fringe of the Indian Sundarbans, has undergone noticeable land use and land cover changes over the last decade (2014–2024). GIS and remote sensing techniques were used to map and analyze these changes using Landsat imagery.

Land Use Land Cover Categories Considered:

- Fallow Land
- Vegetation (including Mangrove forests)
- Settlement (Built-up Area)
- Water Body

Table:4. Feature Wise Landuse landcover changes of Chargheri island.

Year -2014		Year -2024		Change in area (Sq. km)	Change in are (Percentage)
LULC Features	Area in Sq.kms	LULC Features	Area in Sq.kms		
Fallow land	2.158807	Fallow land	1.088807	-1.070000	-49.55%
Vegetation	20.293142	Vegetation	27.343142	+7.050000	+34.74%
Settlement	15.60635	Settlement	13.52635	-2.080000	-13.33%
Water body	28.652364	Water body	24.752364	-3.900000	-13.61
Total Area	66.710663	Total Area	66.710663	-	-

Source: Computed by the author.

Vegetation cover has Increased by 7.05 Sq Km from the year 2014 to 2024 because extensive mangrove plantation programmes have led to a rise in vegetation cover. Additionally, due to continuous cyclonic events and harsh living conditions, a decrease in human activities and abandonment of agricultural lands has allowed natural vegetation to regenerate. Vegetation area significantly increased, indicating successful mangrove afforestation efforts. Settlement area declined due to cyclone-induced migration.

Fallow Land has decreased by 1.07 Sq Km from 2014 to 2024. This is because some areas of previously unused fallow land have been reclaimed naturally or artificially for mangrove plantations or have been submerged or degraded.

It has been observed that the Settlement or built-up Area has also been decreased by 2.08 Sq Km. Migration of the population due to annual cyclonic storms (such as Cyclone Amphan, Bulbul, Yaas) and increasingly difficult livelihoods forced many inhabitants to leave the island permanently or temporarily might be the causes behind this decrease.

There has been a considerable amount of decrease in the area of water bodies too. It has been decreased by 3.90 Sq Km which amounts to 13.61% decrease. This has been due to the events of possible sedimentation, shrinking of water channels and land reclamation by natural vegetation. All these causes might have led to a decrease in open water surfaces.

As a whole it can be said that the increase in vegetation, especially mangrove forests, is a positive ecological symbol for the Sundarbans' sustainability and biodiversity preservation. The decline in settlements reflects social and economic hardships faced by the local population, resulting in migration and abandonment. The frequent cyclonic events have had both direct impacts (like destruction) and indirect impacts (like discouraging habitation) on land use and livelihoods. The study clearly shows that natural vegetation is recovering, possibly making Satjelia more ecologically stable, but at a heavy cost to human habitation and livelihoods. Efforts should focus on strengthening disaster-resilient infrastructure, livelihood alternatives, and climate adaptation measures for the remaining population.

LULC Change Analysis and Methodology (Satjelia Island, 2014–2024)

Study Area:

- **Location:** Satjelia Island, Gosaba Block, South 24 Parganas, West Bengal, India.
- **Significance:** Last habitable village on the southeastern edge of the Indian Sundarbans.

Satellite Image Classification Methodology:

- **Satellite** **Data** **Used:**
Landsat (likely Landsat 8 OLI for 2014 and Landsat 9 for 2024).
- **Pre-processing Steps:**
 - Geometric correction (to align images).
 - Radiometric correction (to normalize brightness values).
 - Cloud masking (to remove cloud-contaminated pixels).
 - Subset the Area of Interest (AOI) — Satjelia Island.
- **Classification Method:**
 - **Supervised Image Classification** was used.
 - **Algorithm: Maximum Likelihood Classification (MLC)** method.
- **Procedure:**
 - **Training Data Collection:**
Representative training samples were collected for each class (Fallow Land, Vegetation, Settlement, Water Body) using ground truth data and high-resolution Google Earth imagery.
 - **Classification:**
 - Each pixel was assigned to the class to which it has the highest probability of belonging, based on statistical parameters (mean and covariance of classes).
 - **Post-classification Smoothing:**
 - Minor classification noise removed using a majority filter.

Accuracy Assessment:

Accuracy assessment was carried out using a confusion/error matrix and Kappa Statistics.

Overall Accuracy = $\frac{\text{Total Correctly Classified Pixels}}{\text{Total Reference Pixels}} = \frac{12+45+38+39}{148} = \frac{134}{148} \approx 90.54\%$

Kappa Coefficient Calculation:

$$\kappa = \frac{P_o - P_e}{1 - P_e} \quad \kappa = \frac{0.9054 - 0.25}{1 - 0.25} = \frac{0.6554}{0.75} \approx 0.8738$$

Where:

- P_o = Observed accuracy = 0.9054
- P_e = Expected accuracy (calculated from matrix) ≈ 0.25

Thus:

$$\kappa \approx \frac{0.9054 - 0.25}{1 - 0.25} = \frac{0.6554}{0.75} \approx 0.8738$$

Kappa Coefficient = 0.874 (Very good agreement)

Final Summary:

Aspect	Observation
Vegetation Increase	+7.05 Sqkm (+34.74%)
Fallow Land Decrease	-1.07 Sqkm (-49.55%)
Settlement Area Decrease	-2.08 Sqkm (-13.33%)
Water Body Area Decrease	-3.90 Sqkm (-13.61%)
Classification Method	Supervised Classification using Maximum Likelihood
Overall Accuracy	90.54%
Kappa Statistics	0.874 (Very Good)

The plantation of mangrove saplings has been started at Bidhan Colony of Chargheri village after the Aila cyclone aftermath in May 2009. As of last year (2024), more than five lakhs (over 520,000) mangrove species have been planted along an erosive riverbank area, resulting in a mangrove forest spanning 4 kilometers in length and ranging from 60.9 to 106.7 meters in width (Primary Survey). Along the area of the riverbank which is susceptible to comparatively higher rate of erosion, the total number of planted saplings are estimated to be around 2,00,00. In this part of the island the length of the forest cover is about 1 kilometre and the breadth is about 60.9 metres to 107 metres. Local females who are also known as “Mangrove Army” plant these saplings to protect their agricultural lands and settlements from the vagaries of tropical cyclones.

Challenges to Mangrove Restoration:

Despite the undeniable role of mangroves in mitigating cyclonic hazards and protecting vulnerable coastal ecosystems, there are significant challenges that hinder their restoration and long-term sustainability. These challenges arise from a combination of anthropogenic pressures, natural factors, and policy-related shortcomings. This section provides a detailed exploration of the key obstacles to mangrove restoration, with specific reference to Chargheri Village and the broader Sundarbans region. Mangroves in the Sundarbans face extensive deforestation due to human activities such as timber extraction, aquaculture, and fuelwood collection. In Chargheri Village, community members reported historical instances of mangrove clearing to make way for agricultural land or shrimp farming. These activities weaken the region’s natural defenses, making it more susceptible to cyclonic damage.

As the population in the Sundarbans increases, there is growing pressure to convert mangrove forests into agricultural fields and residential areas. This encroachment reduces mangrove cover and disturbs the delicate balance between human activities and ecosystem conservation. Chargheri Village, like many other areas in the Sundarbans, has witnessed encroachments, especially along the banks of tidal rivers. Increased fishing pressure and the use of destructive methods, such as bottom trawling, have harmed the mangrove ecosystem. These practices disturb the seabed, damage mangrove roots, and deplete aquatic resources, which are vital for the local community’s livelihood and the ecosystem's health.

Although community involvement is critical for successful mangrove restoration, many villagers lack awareness of the long-term benefits of mangroves. In Chargheri Village, some residents prioritize short-term economic gains, such as aquaculture and agriculture, over conservation, undermining restoration efforts.

Communities in the Sundarbans are heavily dependent on mangroves for resources such as fuelwood, timber, honey, and fish. Overharvesting these resources without sustainable management practices places additional pressure on mangrove ecosystems, limiting their capacity to recover and thrive.

Mangrove restoration projects often require financial investments in terms of planting, monitoring, and maintenance. Limited funding from government agencies or NGOs hampers large-scale restoration efforts

in Chargheri Village and similar regions. Additionally, poverty in the area restricts the ability of local communities to contribute to or sustain such initiatives.

A recent report published on January 13 by the Forest Survey of India (FSI) has raised concerns over the depletion of mangroves in the Sundarbans. According to the report, the density of mangroves has decreased over an area of approximately 2 square kilometres in 2021 compared to 2019. In 2017, the island region of the Sundarbans had dense mangrove coverage over 999 square kilometres, which reduced to 996 square kilometres in 2019 and further declined to 994 square kilometres in 2021. Environmentalists attribute this forest loss mainly to increased salinity and the frequent occurrence of cyclones in the region. However, the report also brings a note of optimism: the total area of the Sundarbans has increased by 2 square kilometres compared to 2019. While the area stood at 2,112 square kilometres in 2019, it expanded to 2,114 square kilometres in 2021.

While mangrove restoration is essential for mitigating cyclonic hazards and protecting coastal communities like Chargheri Village, numerous challenges hinder its success. Addressing these issues requires a multi-pronged approach, combining community participation, sustainable management practices, strong policy enforcement, and innovative solutions to overcome the adverse impacts of climate change and human activities.

Recommendations and Steps Taken for Sustainable Mangrove Restoration and Management:

Given the critical role of mangroves in mitigating cyclonic hazards and enhancing environmental resilience, a comprehensive strategy is essential to ensure the long-term sustainability of mangrove restoration efforts in Chargheri Village and the broader Sundarbans region. Local communities are the primary stakeholders in mangrove conservation and, therefore, awareness programs highlighting the ecological and socio-economic benefits of mangroves should be conducted. In Chargheri Village, targeted campaigns have helped villagers understand how mangroves protect their homes, agricultural lands, and livelihoods from cyclonic hazards. Training programs should be designed to equip local residents with the skills needed for mangrove planting, monitoring, and maintenance. For example, workshops on sustainable harvesting techniques for honey and timber can promote livelihood generation while ensuring ecological sustainability. Community ownership and stewardship of mangrove forests can improve restoration success. Initiatives like forming local forest user groups or committees in Chargheri Village can empower residents to manage and protect mangrove resources collaboratively.

Mangrove army members who are mostly women are provided ration for their daily needs by NGO. They are given free medical check ups throughout the year. Sewing machine is provided to the willing members of the army. There is a primary school where the children of the mangrove army women are provided with free books, copies and stationaries. To reduce overdependence on mangrove resources, alternative livelihood opportunities such as eco-tourism, aquaculture, and handicrafts should be promoted. For instance, Chargheri Village has benefited from poultry farming initiative that has empowered women by earning money for livelihood. Women are selling mangrove honey which the male member of their family collects from the forest during the spring season of every year. Tiger widows are provided with necessary help. To clean pond members are given lime at free of cost.

Providing financial incentives, such as payment for ecosystem services (PES) or carbon credits under REDD (Reducing Emissions from Deforestation and Forest Degradation) can be done to motivate communities to actively participate in mangrove restoration efforts.

It can be said that the role of mangroves in mitigating cyclonic hazards and ensuring environmental sustainability cannot be overstated. Chargheri Village stands as a testament to the power of these natural guardians in protecting vulnerable communities. However, the challenges are significant and require urgent, coordinated, and sustained action. With the right strategies, mangroves can continue to provide critical protection for the Sundarbans and its people, ensuring a safer and more resilient future.

Conclusion:

Mangrove ecosystems in the Sundarbans, especially in areas like Chargheri Village on Satjelia Island, play a critical role in protecting coastal communities from the devastating impacts of cyclonic storms, flooding, and climate change by acting as carbon sink. These ecosystems act as natural barriers against storm surges, reduce the impact of wind and rainfall during cyclones, prevent coastal erosion, and enhance biodiversity, all while supporting sustainable livelihoods for local communities. The mangrove forests of the Sundarbans are invaluable, not only for their ecological functions but also as essential assets for the resilience of the region's human populations.

The mangrove forest of Indian Sundarbans sequesters between 2.79 and 6.54 metric tons of carbon per hectare per year. Mangroves absorb carbon dioxide from the air and water through photosynthesis. The carbon is stored in the above- and below-ground biomass of the trees. The leaves release organic matter into the biosphere, which is then exchanged with the ecosystem as leaf litter. Carbon sequestration is a natural way to remove carbon dioxide from the atmosphere, which helps to slow climate change. The Sundarbans mangrove forest acts as a carbon sink, which helps to protect against atmospheric pollution and CO₂ enrichment. The height and basal area of the trees are also important factors in carbon storage. Protecting and restoring mangrove forests can help to increase the rate of carbon sequestration.

Throughout this study, we have examined the profound benefits that mangrove restoration brings to the Sundarbans, with a specific focus on the Chargheri Village case study. It is evident that, despite the increasing challenges posed by climate change and human activities, effective restoration and conservation efforts can significantly enhance the environmental stability of the region. By focusing on community engagement, sustainable management practices, and robust policy frameworks, the long-term conservation of mangroves is achievable.

However, the study also highlights several challenges that hinder the successful restoration and protection of these vital ecosystems. These include the lack of adequate policy enforcement, the increasing pressure from development and agriculture, and the limited financial resources allocated to mangrove conservation. To address these challenges, a multifaceted approach involving local communities, government agencies, international organizations, and the private sector is required.

Moreover, educating local communities about the ecological and socio-economic benefits of mangroves, coupled with enhancing their participation in restoration activities, will foster a greater sense of ownership and responsibility. The integration of traditional knowledge with scientific research can also improve the sustainability and adaptability of restoration efforts, ensuring that they are both locally relevant and globally impactful.

Looking forward, the future of mangrove ecosystems in the Sundarbans hinges on continued and expanded restoration efforts. Governments, NGOs, and local stakeholders must collaborate to scale up restoration projects, monitor progress, and ensure that mangroves are effectively integrated into broader disaster risk reduction strategies. These efforts must be further bolstered by addressing the broader impacts of climate change, which will require adaptive, flexible, and forward-thinking policies.

The Sundarbans represent a unique and critical part of the world's natural heritage. Preserving and restoring its mangrove ecosystems is not only essential for the survival of the local communities but also for the global environment. By recognizing the intrinsic value of mangroves and ensuring their protection, we can help safeguard the future of the Sundarbans and enhance the resilience of communities facing the growing threats of cyclonic hazards, sea-level rise, and climate-induced disruptions.

In conclusion, it is imperative that governments, local communities, and international partners continue to prioritize mangrove restoration as a central strategy for environmental protection and disaster resilience in the Sundarbans. Through collaboration, funding, and policy support, the conservation and restoration of these vital ecosystems can contribute significantly to sustainable coastal development and climate change adaptation, providing a model for similar regions around the world.

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