Protection of coastal areas and earthen embankment through vegetative solutions

Report of the Expert Committee

Report of the Expert Committee

July 2021

Environment Department,
Government of West Bengal.
July 2021.

Protection of Coastal Areas and Earthen Embankment Through Vegetative Solutions

Contents

Foreword

The protection of embankment through Bio-Shield is a new concept. But for obvious reasons, it might take more than a decade to create such a green wall. Thus, adopting the Bio-Shield approach does not mean discarding civil engineering approach, it rather interprets into laying emphasis on the inclusion of both soft and hard solutions as well as a hybrid of the two, as options of protection. The coastal districts of West Bengal were devastated by a severe cyclone named YAAS on the 26th of May 2021. The unfortunate coincidence of the time of high tide and landfall of cyclone with wind speed more than 135 km. generated high waves over the Bay of Bengal and the swelling water breached/overtopped both the coastal dykes and river embankments. More than 297km. river embankment and 21km. sea-dykes were damaged. No less than 452 km^2 area belonging to three coastal districts (Purba Medinipur, South and North 24 Parganas) was submerged. The waves, both in the Sea and rivers achieved such an alarming height that the embankments proved futile in protecting the riparian people. The four sea-facing islands of the Sundarban namely Sagar, Moushuni, Namkhana and G-Plot along with 41km. long coastal belt of Purba Medinipur were severely damaged.

The recurrent breaches in the earthen embankments are an age-old problem in the coastal districts. The palliative works like plugging or strengthening the embankment have not ensured freedom from flood. It is now realized that we need to explore an alternative solution. In this backdrop, the Department of Environment, Government of West Bengal, vide its notification no. 016/ECSENV/2021 dated, June 02, 2021, constituted an Expert Committee consisting of 24 experts belonging to different disciplines. The Committee met twice and also interacted through emails. The members were requested to submit their reports on ‘Protection of Coastal Areas and Earthen Embankments through Vegetative Solutions’ and the experts expressed their valued opinion in due time. The engineers of the Irrigation and Waterways Department were also consulted to share their experiences and archival data. This is a compilation of all reports in a comprehensive form.

It would have been impossible to present this report without generous help and inputs from many other Experts. We are especially grateful to Dr. Subrat Mukherjee, PCCF & HOFF, Sri V.K. Yadav, PCCF, Sri Saurabh Chaudhuri, Additional PCCF, Prof. Subhamita Chaudhuri, Department of Geography, West Bengal State University, Dr. Himadri Sekhar Debnath, former Joint Director, BSI, Sri Dibyendu Sarkar, Former Secretary Panchayet Department and Dr. Sayantan Das, Assistant Professor, Dum Dum Motijheel College. Last but not least, we are thankful to Dr. Kaberi Samanta and Sri Abheejit Chakraborty for cartographic assistance.

Dr. Kalyan Rudra

Chairman

Executive Summary

The Hugli estuary divides the southern sea-front of West Bengal into two distinct geomorphic units. The 41km stretch of Purba Medinipur between Subarnarekha and Pichhabani river and 30km. long stretch four islands of the Sundarban (Sagar, Moushuni, Bakkhali and G-Plot) are extremely vulnerable and frequently damaged by cyclonic surges. Further, the eastern boundary of Purba Medinipur is delineated by 80 km. long river-front from the Pichhaboni to Rupnarayan estuary. The Sundarban is an area of complex drainage network and favours the largest mangrove eco-system which has been declared as World Heritage Site. As the pre-mature land stands between -2 to + 1.50 m. in respect of the mean sea level and all the rivers swell between 2 to 2.70 m. due to regular tidal fluctuation, the earthen embankments were built along the banks of rivers to protect the floodplain from the tidal submergence during the Raj-era. The embankments were built along 3500 km.-long river bank but now the length of effective embankments is not more than 1800 km. The recurrent breaches in the embankment and overtopping are common, especially when landfall time of a cyclone coincides with the high tide. The swelling water may gain an additional height of 3-5 m. and devastate the coastal tract.

The Global Mean Sea Level has been rising @ 3.6 mm/year between 2006-2015. The sea level off the coast of Bengal is rising @4.04±0.44 mm/year. The impact of sea level rise in Sundarban is further accelerated due to slow subsidence of land @2.9 mm/year. Since 2009 four Cyclones have devastated the coastal Bengal. These are Aila (2009), BulBul (2019), Amphan (2020) and Yaas (2021). In all those cases, wide spread inundation of the coastal villages due to breaking/ overtopping/collapsing of the embankment, and large-scale destruction of human settlements were common. But the experiences on 26 May 2021 surpassed all records in recent times, as landfall time of the Cyclones coincided with high tide, which achieved an alarming height of 7.50 m. at Sagar Island and the wind speed was between 130-140km/hour which dragged the swelling water over the littoral tract. The 452 km^2 waterlogged areas due to the Yaas, were identified from a couple of Sentinel 1A RADAR images that captured the scenes between 5:40-5:45 pm on that day. It was observed that 297 km. river embankment and 21 km. sea-dykes were damaged.

To date we relied exclusively on civil engineering measures to repair damaged/breached embankments but present expert committee proposed the vegetative solutions. The experts have proposed to create multi-layer vegetative shield, three in front and two in landward side of the river embankment of Sundarban. We hope this new approach will ensure better safety of embankments. But creation of a proper vegetative wall may take more than a decade; till then we have no other alternative but to adopt the civil engineering measures to protect the embankments. The Irrigation and Waterways department has identified 378 stretches of different rivers having a total length of 559 km. as vulnerable, of which 207 stretches having a combined total length of 324 km. have been marked as being extremely vulnerable. These are mostly east-facing concave banks where the possibility of beaching/overtopping of embankment in future cannot be ruled out. The creation of a second line of defence in the form of circuit embankment in the landward side will offer additional safety to the people in case of breaching of the frontal embankment. The area lying in between must be used for creating a vegetative shield. While creating the circuit/retired embankment, the soil may be borrowed creating ponds or water bodies. The excavation of moribund channels may serve the dual purposes of rain water harvesting and the earth thus generated may be used for embankment building. The fresh water accumulated in the rejuvenated channel will also change the face of rural economy.

The sea-facing islands of Sundarban are shrinking in size, and the coast of Purba Medinipur are eroding at an average rate of 5 m./year. The beach and sand dunes replenish each other through movement of sand; but intervening concrete embankment has interrupted the mutual relationship leading to lowering of beach In this scenario of changing climate, it impossible to resist the aggression of sea-wave through on shore intervention. There is hardly any scope of creating a bio-shield where the beach is narrow. In the 30 km.-long sea-front of four inhabited islands (Sagar, Moushuni, Bakkhali-Namkhana, and G-plot), reinforcement of the existing embankments with concrete and their protection with thoughtfully planned vegetative buffers should work well to prevent overtopping of storm surges. In erosional and exposed localities, it is also important to construct two parallel dykes with cross-embankments put at regular intervals between them to prevent widespread flooding of the interiors in the events of beaching or wave-overtopping of the outer embankments. If the frontal old embankment is located along the High Tide Line (HTL), the buffer area between the old and new dykes may ideally be 200 m and should be declared as ‘no construction zone’ in compliance with the Coastal Zone Regulation (2019). Further the eroded beaches in both Purba Medinipur and Sundarban have become so narrow and low that the wave-breaking zones have come closer to the land. Since there is hardly any area along the southern front of Sagar Island to create a proper bio-shield, an artificial off-shore reef barrier proposed by the experts of IIT-Madras may be effective to reduce intensity of coastal erosion. The Irrigation Waterways Department is also considering the issue of such off-shore intervention to protect the tourist hub of Purba Medinipur between New Digha and Pichhabani inlet. Further, the Department of Forest has started the work of creating three-layer green walls along the eastern boundary of Purba Medinipur. The new approach as recommended by the experts will combine both hard and soft engineering to protect the extremely vulnerable coastal tract of West Bengal.

Prelude:

The coastal tract of West Bengal extends from Ramnagar (Purba Medinipur) in the west to Haribhanga river on Indo-Bangladesh Border in the east, having a length of 200km. The Hugli estuary divides the coastal West Bengal into two distinctly different parts (Figs.1 & 2). The littoral tract between Gangasagar and Indo-Bangladesh border is very dynamic and fast changing. The length of coastline measured along Land-Sea front is 41km in Purba Medinipur (Subarnarekha to Pichhabani) and along the southern face of four islands (Sagar, Moushuni, Bakkhali and G-plot) it is 30km.The afore-mentioned stretch of Purba Medinipur also has a long history of shoreline erosion, though the stretch between Jatra Nala and Digha Mohana is protected with concrete embankment (Chaudhuri, 2021).

The littoral tract of the Sundarban is also called active delta where fluvial and marine land building processes are working together. The silt-laden water in rivers spills over the inter-tidal space and goes back twice in 24 hours leaving behind layers of sediment on the floodplain. This is the youngest terrain which was reclaimed in phases since the late 18th century to facilitate farming and human habitation during the Colonial period. The Sundarban is an area of complex drainage network and favours the largest mangrove ecosystem which has been declared as World Heritage Site. The dense forest covering 54 islands in western Sundarban were cleared with the help of labourers brought from erstwhile Medinipur and Chhotanagpur plateau. It is important to note that number of habitable islands is now reduced from 54 to 35 due to decay of many intervening channels which earlier bifurcated some islands. As the pre-mature land stood between -2 to + 1.50 m. in respect of the mean sea level and regular tidal fluctuation was found to vary between 2 to 2.70 m., the earthen embankments were built along the banks of rivers to protect the floodplain from tidal submergence. The earthen structures were built along 3500km. long river bank, but now the length of effective embankments is not more than 1800 km. In an uncontrolled fluvio-marine regime, the coastal tracts slowly gain height as each high tide leaves behind sediment layers on the inter-tidal space (i.e., the area between the high and low-tide line). The embankments impaired normal sediment dispersal process and the rivers were compelled to deposit the sediment load on the beds reducing the water-holding capacity. While the river beds were gradually elevated, adjoining flood plains were deprived from accretion of sediment. As the process continues till date, the high tide achieves a height far above surrounding villages (See Fig. 3 and Fig. 4).

Thus, breaches in embankment and overtopping are common, especially when landfall time of a cyclone synchronises with the high tide. The swelling water gains an additional height of 3-5 metres and devastates the coastal tract (Fig. 5). On the contrary, sediment deposition continued in the non-reclaimed forest areas and consequently the area stands at a higher level (+1 m.) on an average than the reclaimed areas. The Indian Sundarban is thus divided into reclaimed and non-reclaimed parts (Fig. 6). The reclaimed Sundarban in West Bengal comprises six C.D. Blocks of North 24 Parganas and 13 C.D. Blocks of South 24 Parganas covering a total area of 4,575 km^2, of which 2,988 km^2 area is used for agricultural purposes. The net forest excluding water area covers an area of 2,220 km^2.

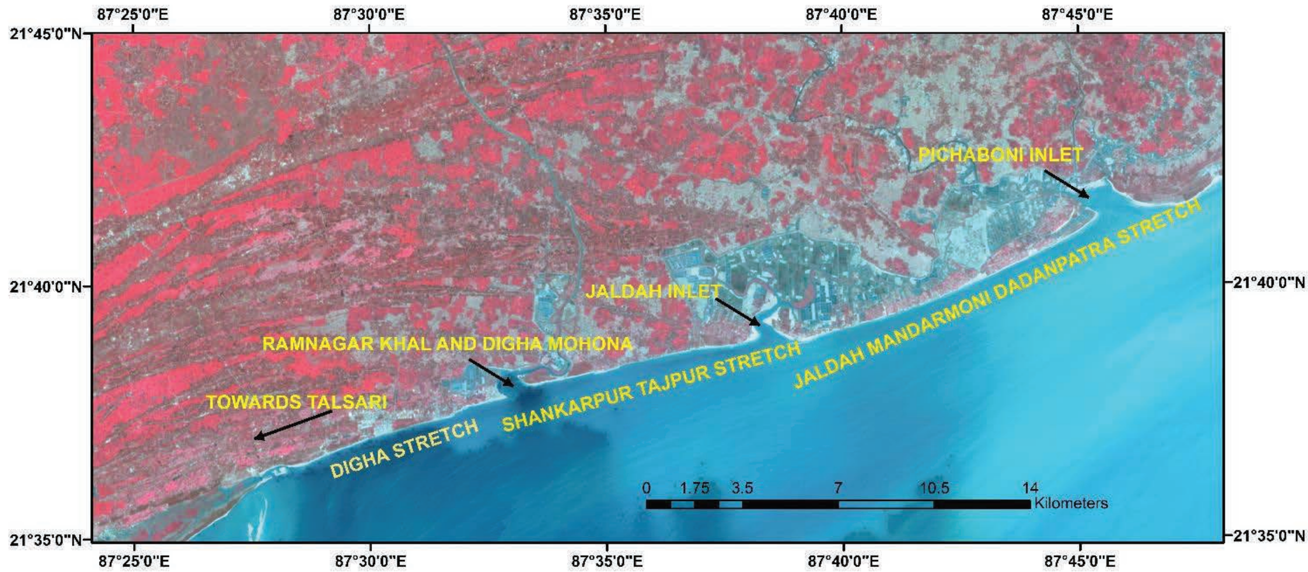


Fig. 1 The Coastal tract of Purba Medinipur

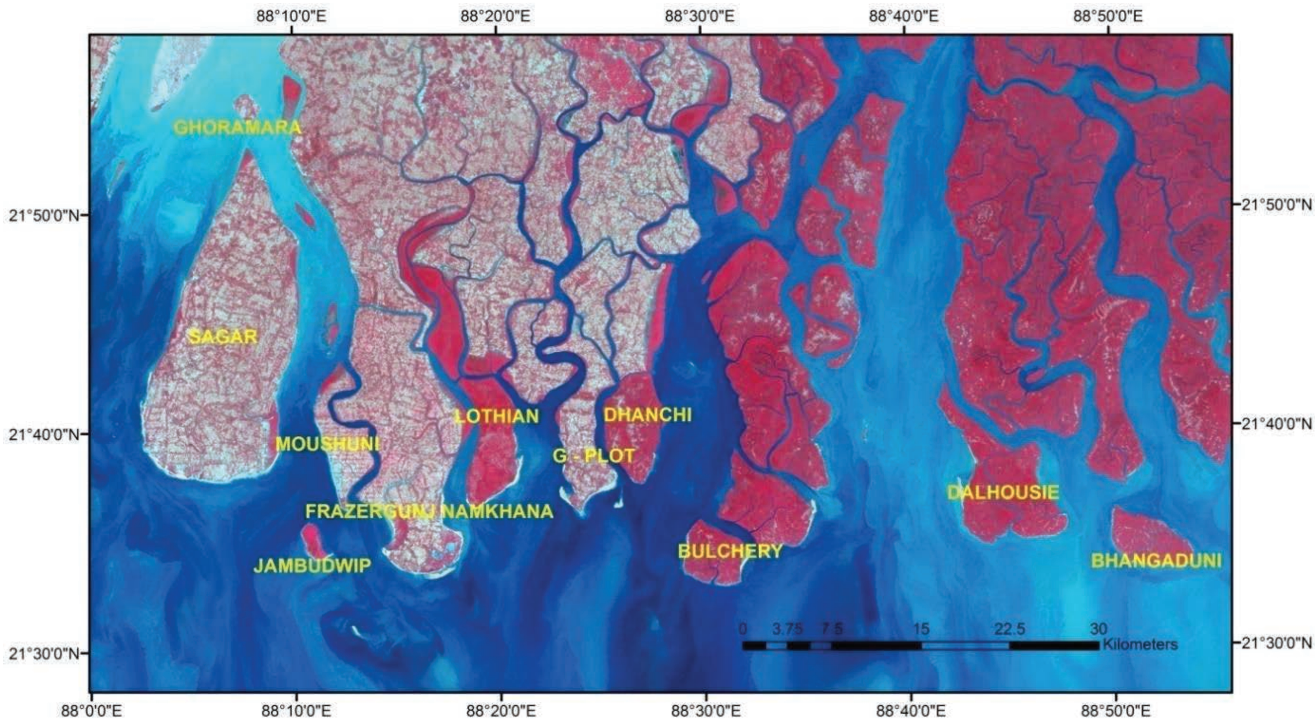


Fig. 2 The Coastal Islands of Sundarban

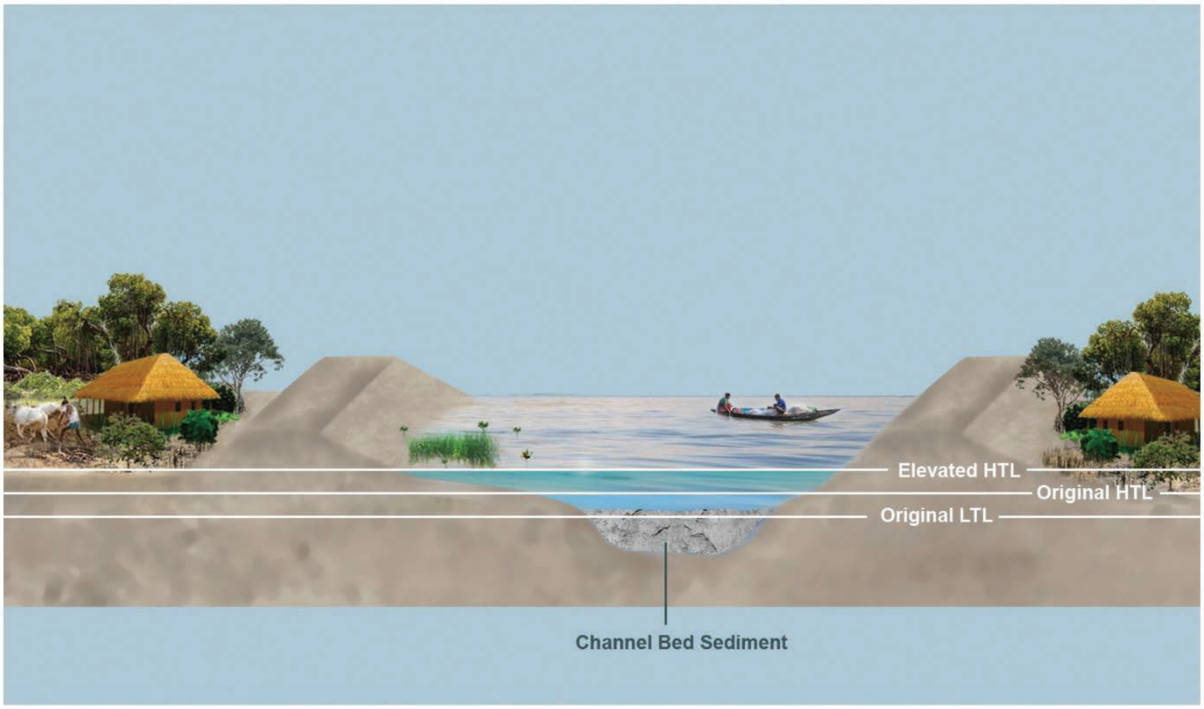


Fig. 3 The sedimentation on embanked river bed and elevated high tide level.

Fig. 4 During high tide the river rises to a height above the adjoining floodplain

Fig. 5 Overtopping of coastal embankment

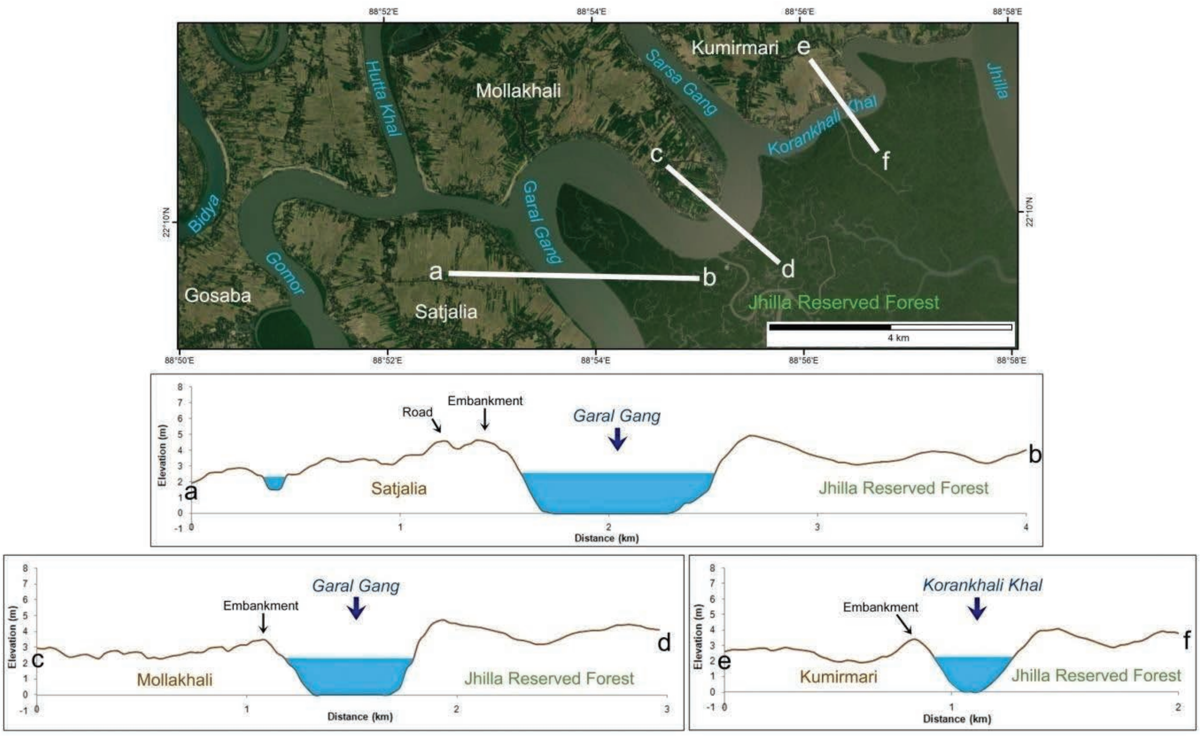


Fig.6. Digital Elevation Model-derived cross profiles showing differential elevation of reclaimed and non-reclaimed Sundarban

The 19 blocks, 6 in North 24 Parganas and 13 in South 24 Parganas, together render homes to 4.5 million people. In spite of appreciable negative impacts, the embankments are undoubtedly the lifeline of about three million people living on the waterfront of the Sundarban. The armoured or concrete embankment is a popular demand but such structures may be resistant to erosion but cannot resist overtopping of swelling water.

The coastal tract of East Medinipur, especially sea-front zones of Digha, Mandarmani and Tajpur is the growing tourist hub of West Bengal. The Coastal Zone Regulation Notification (2011), declared the area lying within 500 m. from the high tide line as 'no construction zone' and the subsequent amendment of 2019 reduced this restriction zone to within 200 m. But it has been observed that many hotels/resorts of Mandarmani have grown violating CRZ regulation and running without any consent from competent authority. The sand dunes with natural vegetation offers protection to coastal tract but such barriers were drastically modified to promote the commercial activities. Consequently, the sea took to encroaching inland. The rising sea level and frequent aggression of cyclones have further aggravated the situation. The high waves crossed the strongly built embankments of Digha and devastated the township when the cyclone Yaas was approaching the coast.

Sea-Level Rise and Frequent Storm Surge:

The Indian Ocean favours cyclogenesis due to its location. In the changing meteorological condition, the frequent advent of Cyclones coupled with sea level rise leads to coastal erosion, breaches in the embankment and 80% of cyclones formed over North Indian Ocean between 1877 to 2016, moved over the Bay of Bengal, and 40% of which struck coast of Bengal and Odisha (Bandyopadhyay et al., 2021). The increasing sea-surface temperature (SST) is one of the reasons which facilitates accelerated evaporation, rainfall and also formation of cyclones. The SST in Bay of Bengal has been increasing at the rate of 0.5° C/decade since 1980 while the global average is 0.06° C/decade (CSE, 2012). While discussing the issue of sea level rise, the report of Intergovernmental Panel on Climate Change (IPCC) is frequently referred by Scholars. The IPCC (2013) noted that rise of global mean sea level was 1.7 mm/year between 1901-2010 but increased to 3.2 mm/year between 1993-2010.

The Global Mean Sea Level (GMSL) rise was further accelerated to 3.6 mm/year between 2006-2015 (IPCC, 2019). It is observed from the analysis of satellite altimetry data (sealevel.colorado.edu) that sea level off the coast of Bengal has been rising @ 4.04 ± 0.44 mm/year (Bandyopadhyay, 2019). The impact of sea level rise in Sundarban is further accelerated due to slow subsidence of land @ 2.9 mm/year (Brown and Nicholls, 2015).

The cyclonic storms frequently ravage the littoral tract of Bengal. In this era of Climate Change, cyclones are striking the coast of Bengal more frequently, causing huge damages to ecosystem and society. Since 2009 four Cyclones have devastated the coastal Bengal. These are Aila (2009), BulBul (2019), Amphan (2020) and Yaas (2021). In all those cases, wide spread inundation of the coastal villages through breaking/overtopping/collapsing of the embankment, large scale destruction of human settlements, casualties and saline water submergence of agriculture land, making them unsuitable for cultivation were common. Further, whenever landfall time of the Cyclones coincided with high tide, the consequent damages had larger magnitude. Such unfortunate coincidence happened in cases of Aila, Bulbul and Yaas. But the time of landfall of Amphan near Lothian Island synchronised with the low tide and consequently damages were less, though it belonged to the category of ‘Very Severe Cyclone’ with the wind speed of 110-120 km./hour gusting to 130 km./hour at landfall (See Table 1). It is important to note that the Cyclones passing over coastal Bengal always moves in an anti-clockwise circuit. When the cyclone moves north or north-eastwards over the littoral tract, the wind blows from east to west in Sundarban. This is locally called ‘Easterly Wind’ or ‘*Puber Haoa’*. The residents of Sundarban have learnt from their past experiences that ‘easterly wind’ indicates forthcoming disaster. This wind, while blowing over north-south aligned estuaries causes swelling of water and ultimately leads to overtopping or breaching of embankment along west bank. The stretch of estuaries extending up to 7km. from the coast is generally worst affected. The embankments are more vulnerable along the concave banks where *thalweg* or the deepest part of the channel has reached closer. The frequent breaches and overtopping of embankments along the right or western bank of south flowing estuaries may be attributed to afore-mentioned causes. The locations of many breached embankments caused by the Yaas corroborate the view expressed above. The submergence of Haldia and Digha during landfall of Yaas was largely due to such fast-flowing wind which created high and destructive waves. The HTL at Sagar at 9.15 am on the 26th of May, 2021 achieved an alarming height of 7.50m, when outer cloud-wall region of the Yaas having a radius of about 250-300 km. had touched the coast line of East Medinipur and the Sundarban. The wind speed was between 130-140 km./hour gusting to 155 km./hour. The onrushing wind dragged the water-level 2-3 metres above the HTL. It has been reported by the victims that two metres high wave generated from the Muriganga swept away the Ghoramara island. Even senior citizens of Ghoramara never experienced such high wave devastating the islands. The islands of Gosaba, Kumirmari and Moushuni were marooned extensively. The waterlogged areas due to Yaas, extracted from a couple of Sentinel-1A RADAR images, captured the concerned areas between 5:40-5:45 pm on 26 May 2021, i.e. exactly 9 hours after the landfall. Permanent waterbodies in the form of vector layers were not shown in any of the maps prepared from images (See Figs. 7-19).

The lessons learned from our experiences demand a relook into the ongoing management plan and explore sustainable options of protecting the hydro-geomorphologically sensitive area. To date we relied more on civil engineering measures to repair damaged/breached embankments but present expert committee proposes to harmonise civil engineering with vegetative solutions. This may be described as ecological engineering (Mitsch, 2012). We hope this new approach will ensure better safety of embankments. But creation of a proper vegetative wall may take more than a decade; till then we have no other alternative but to adopt the civil engineering measures to protect the embankments.

Table 1: Recent Cyclones affecting the coastal West Bengal

Cyclone	**Date/ time/ location of landfall**	**Wind speed (km/hour)**	**Time of High Tide (IST)**	**HTL at Sagar (M)**	**Category**
*Aila	25 May, 2009; 13.30 to 14.30. Close to Sagar	110-120 km. gusting to 130 km/hr at landfall	12.50	4.20	Severe Cyclone
*BulBul	9 November, 2019; 20.30 to 21.30. Dhanchi island	110-120 km. gusting to 135 km/hr at landfall	20.29	4.77	Severe Cyclone
Amphan	20 May, 2020; 15.30 - 17.30 . Lothian island	155-165 km. gusting to 185 km/hr at landfall	20.44	4.67	Very Severe Cyclone
*Yaas	26 May, 2021; 10.30-11.30. Dhamra(Balasore)	130-140 km. gusting to 155 km/hr at landfall	9.15	7.50	Very Severe Cyclone

Source: IMD and SPMP, Kolkata. *The time of landfall coincided with the high tide.

Table 2: Damages to the Flood Management Infrastructure

Districts	Length of damaged river-embankments	Length of damaged sea dykes	Breaches in river-embankments		Breaches in sea dykes		Total number of damaged structures: (sluices, inlets, regulators
	Km	Km	No.	Km	No.	Km	(No.)
Purba Medinipur	59.64	12.00	NIL	NIL	NIL	NIL	110
South 24 Parganas	181.13	9.25	142	3.93	6	0.66	7
North 24 Parganas	56.63	NIL	137	3.50	NIL	NIL	NIL

Source: Department of Irrigation &Waterways.

Table 3: Inundated area as monitored Satellite Image

District	Total area (km^2)	Inundated area (km^2)
Purba Medinipur	4736	237.8
South 24 Parganas	9960	154.9
North 24 Parganas	4094	59.4

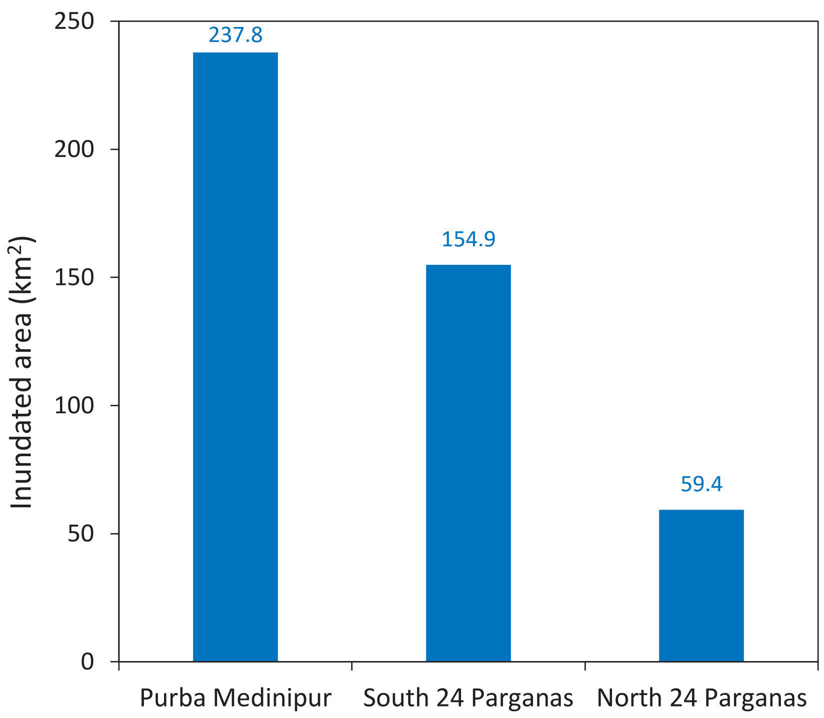


Fig. 7 Inundated areas in three districts due to the landfall of Yaas, 26 May 2021

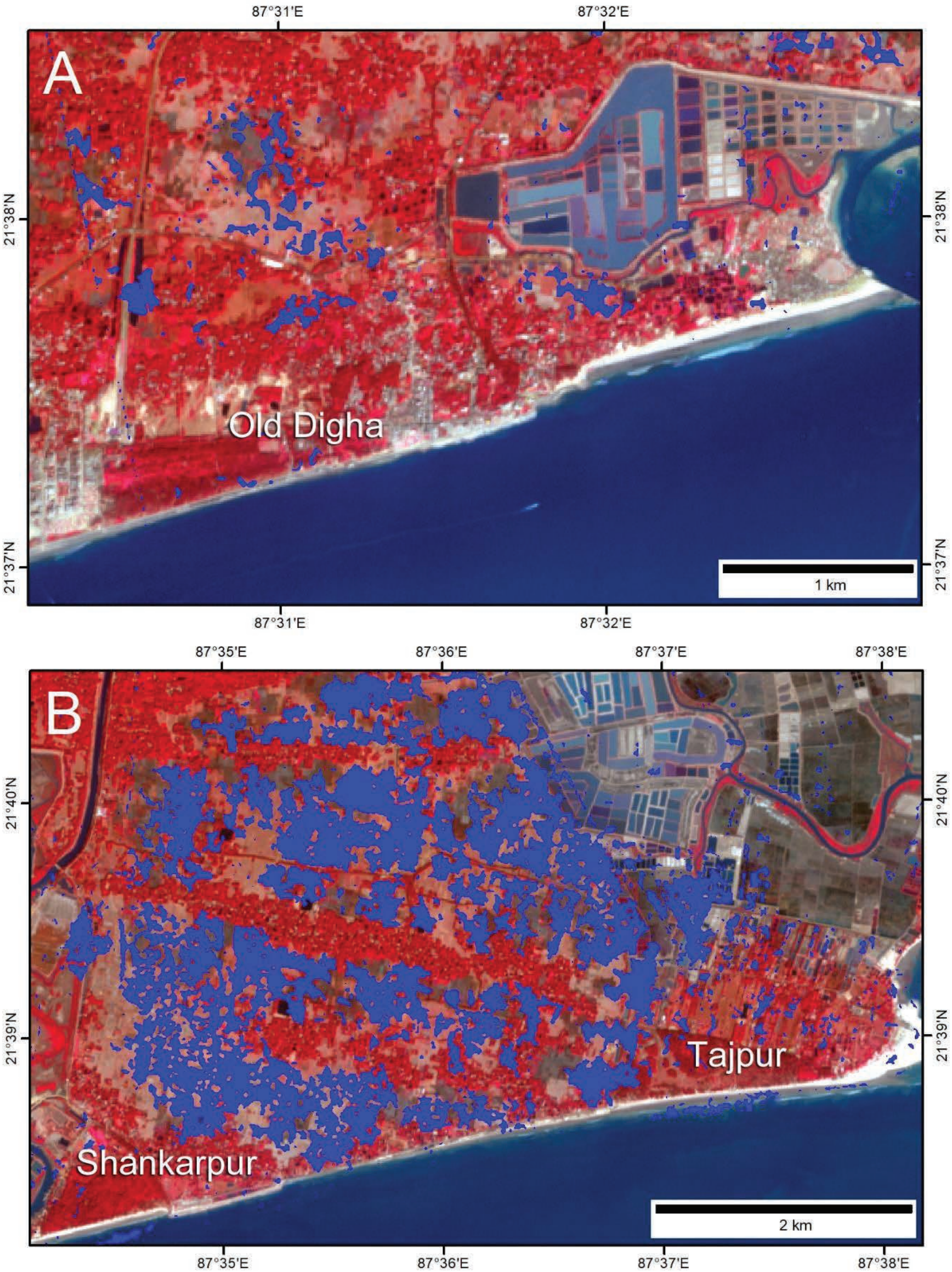


Fig. 8 Old Digha (A) and Shankarpur-Tajpur (B)

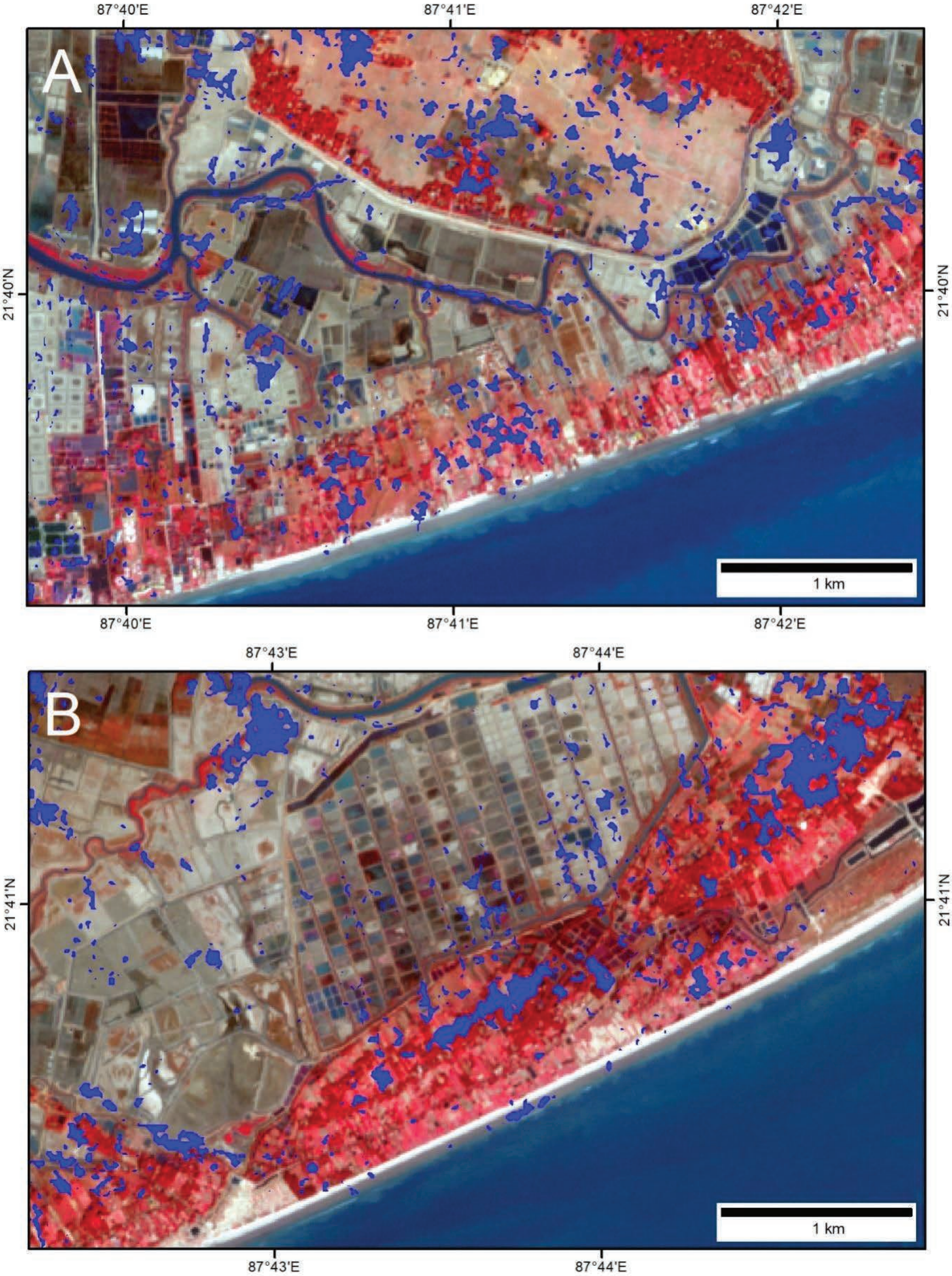


Fig. 9 Mandarmani west (A) and Mandarmani east (B)

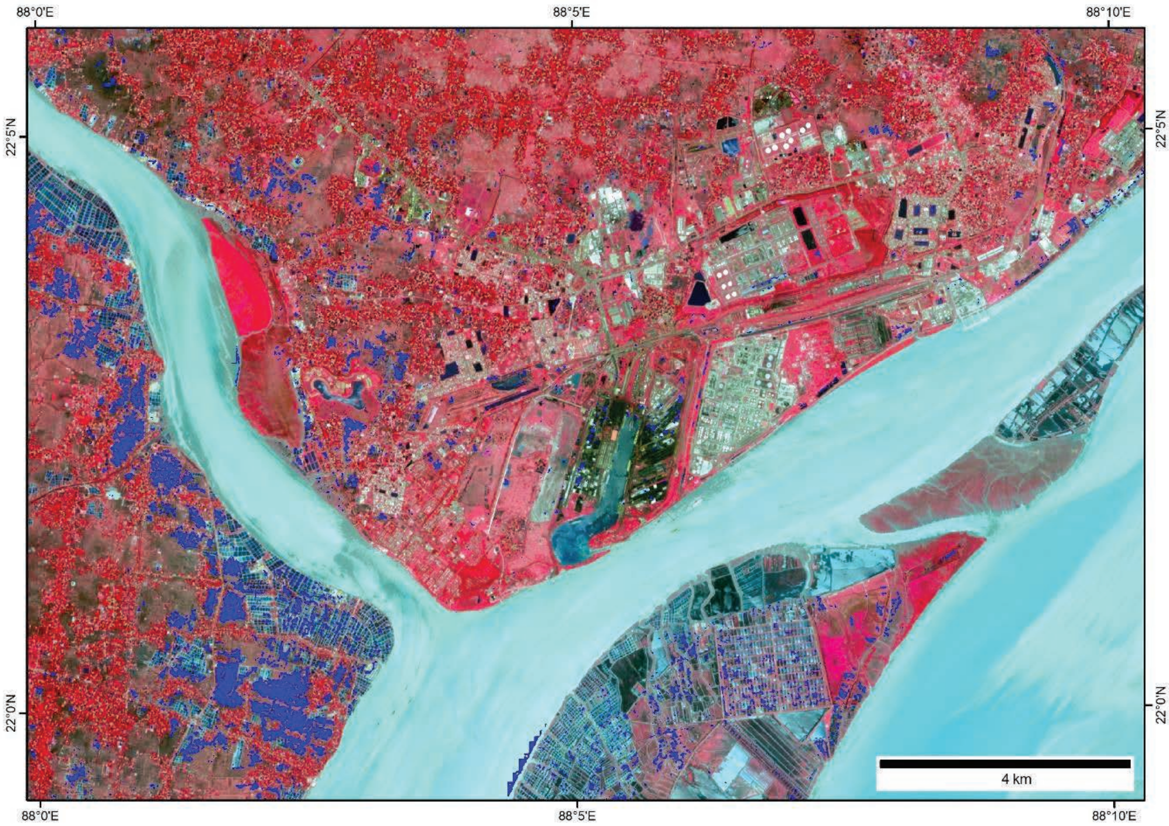


Fig. 10 Haldi Estuary

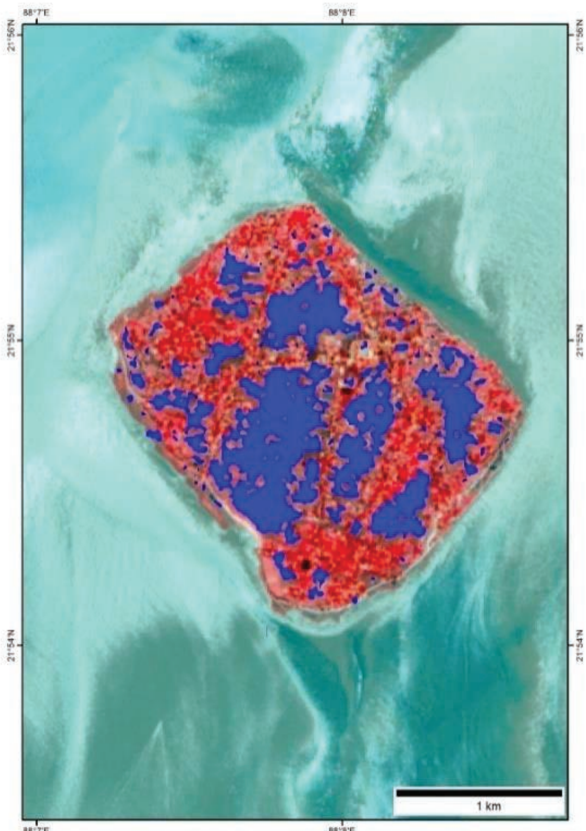


Fig. 11 Ghoramara Island

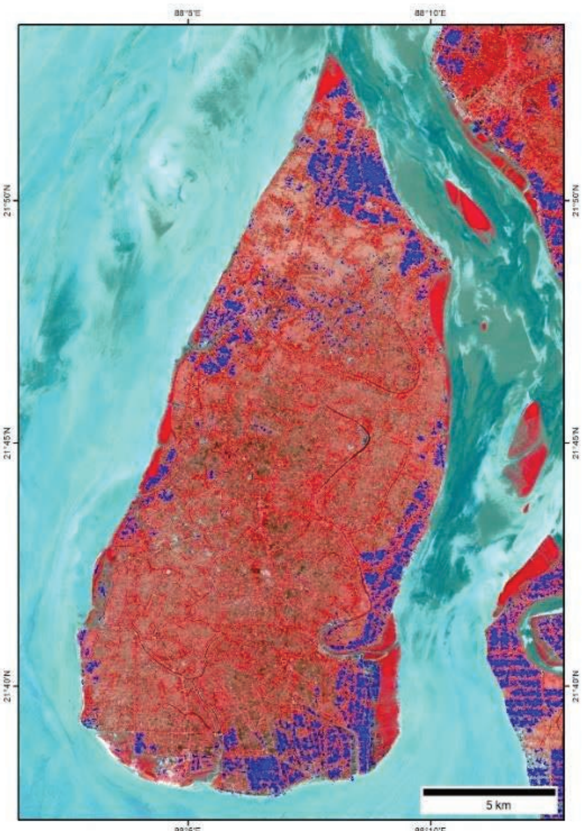


Fig. 12 Sagar Island

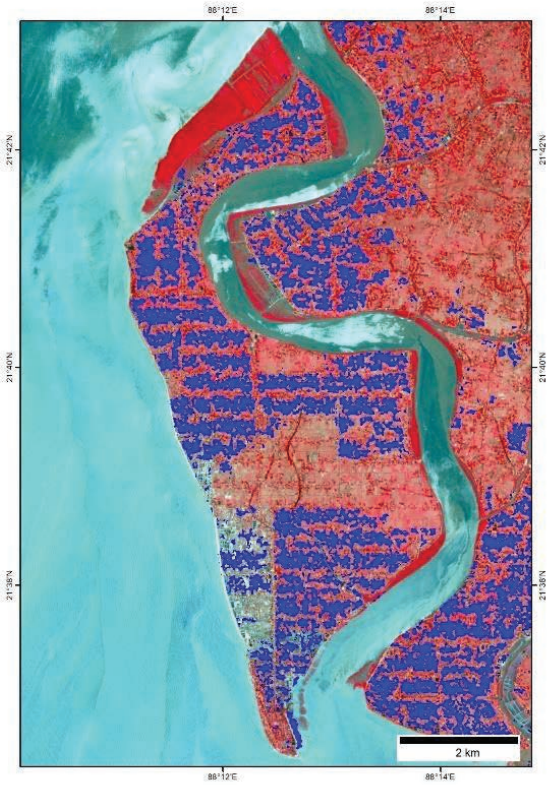


Fig. 13 Moushuni Island

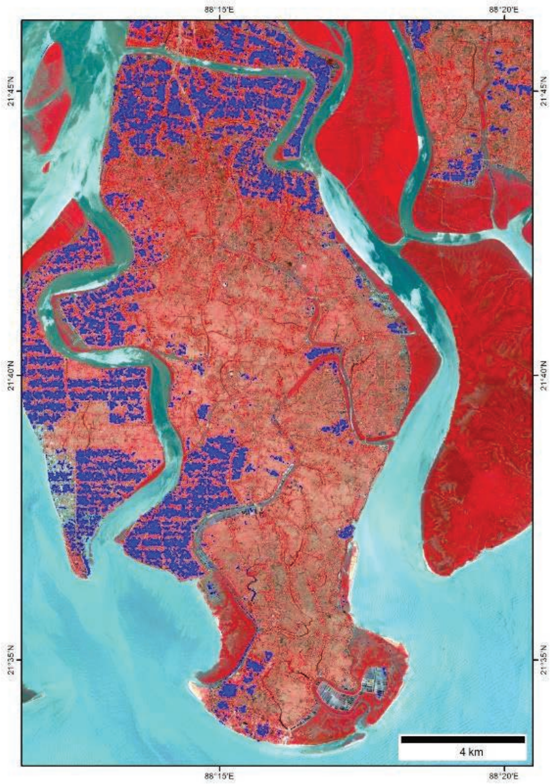


Fig. 14 Namkhana Island

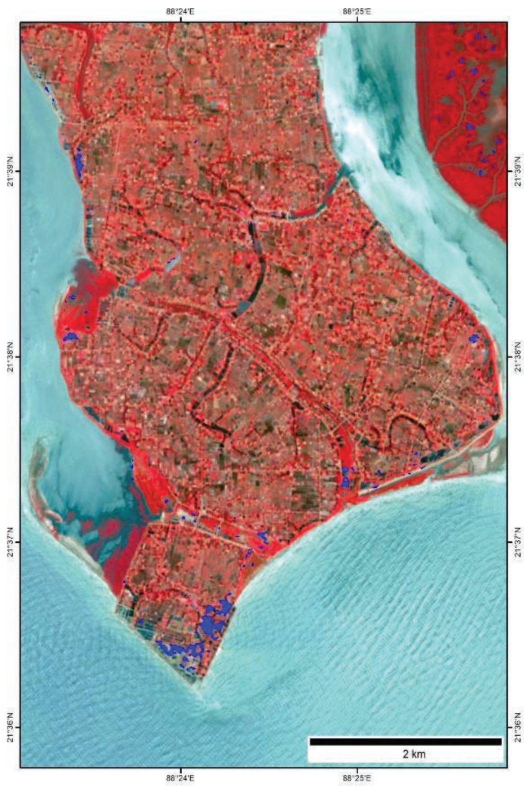


Fig. 15 G-Plot

Fig.16 Gosaba Island

Fig. 17 Chhoto Mollakhali Island

Fig. 18 Kumirmari Island

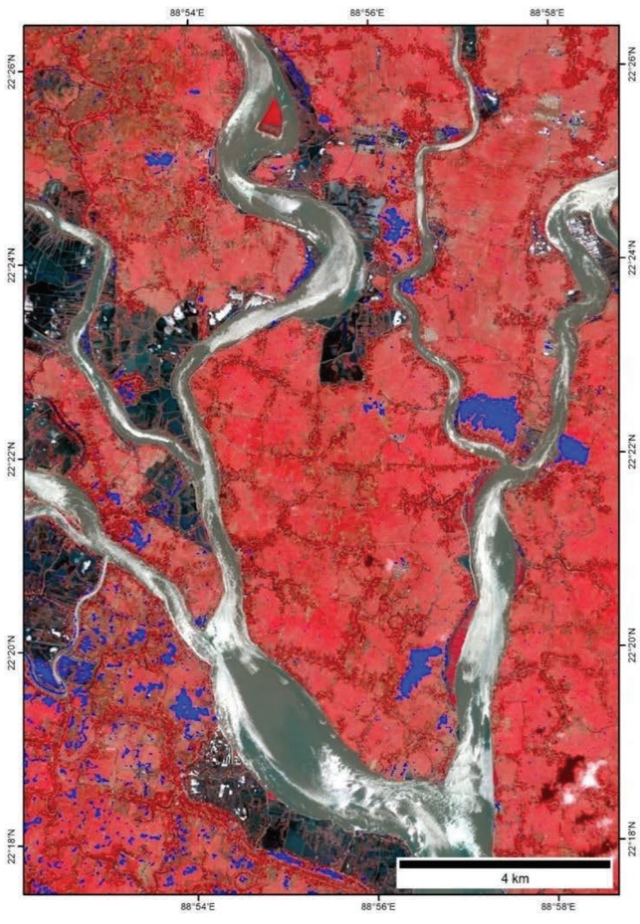


Fig. 19 Sandeshkhali

Condition of river-embankments

The embankment lying within a distance of 7 km. from the Bay of Bengal are subject to higher wave attacks. This stretch was identified as Zone I by the Committee of Technical Experts (2021) and embankments in this zone should ideally be located at the outer limit of tidal expansion of the creeks. It is observed that 90% stretches of embankment in Sundarban, are low-height earthen structures having crest width around 2.5 m. to 3.5 m. and elevation of 2.5 to 3 m. above existing ground level (4.5 m. to 5.0 m. above Mean Sea Level). Though constructed within intertidal space, these embankments can sustain the impact of normal tides but face overtopping in case of high waves during severe cyclones. Such overtopping causes washing out of upper part of embankments, ultimately leading to breaches and total collapse. The collapse of embankment due to under-scouring along the concave banks is also common. The impact of waves is more dominant along concave banks where there is no mangrove on inter tidal spaces, which could at least absorb a part of the kinetic energy of the rolling waves. On the other hand, about 364km long armoured embankments have crest width around 3.5 m. to 4.5 m. and a height of about 4.5 m. to 5.0 m. above existing ground level (6.5 m. to 7.0 m. above Mean Sea Level). The embankment is built up by earth but have bigger base width and quite flat riverside slope (at 18º or even less). The slope is protected /armoured by concrete or brick block pitching for resisting the impact of the breaking waves. Quite often the frontal *char* is protected or widened by deflectors and other anti-erosion devices, mostly bamboo cubicles with protrusions, known as porcupines, filled up with bricks to add weight. These types of embankments have successfully resisted overtopping and failure during "Amphan" as well as "Yaas" in the entire area across Sundarban. However, these are quite cost prohibitive (around Rs 14 crore per km. for river embankment) and require at least 20m -25m of additional private land in the countryside. The unfortunate coincidence of the Yaas's landfall with high tide damaged about 297 km.-long river embankment in three coastal districts. In addition, there have been breaches at 285 locations (total breach length 8.09 km.). The 21km. long sea-dykes in Purba Medinipur and 24 Parganas (South) have also been damaged. Further in all three affected districts, the brick field and *bheries* (fish pond) have inlets to withdraw water from the rivers. Many of such inlets allowed onrushing water to submerge human settlements. All such artificial conduits must have regulator to control spill off during forthcoming cyclones.

The irrigation and Waterways department has identified 378 stretches of different rivers having a total length of 559 km. as vulnerable, of which 207 stretches having a total length of 324 km. as extremely vulnerable (See Annexure 1A & 1B). These are mostly east-facing concave banks where the possibility of beaching/overtopping of embankment in future cannot be ruled out.

It is rather difficult to do reconstruction of *pucca* embankments to the required scale due to financial and other constraints. In such a scenario, a series of measures can be considered for adding durability to the existing earthen embankments. These vulnerable stretches are mostly along concave banks where *thalweg* or deepest part of channel has reached close to bank and there are hardly any berm or inter-tidal spaces along the river-front. The use of deflector cum silt arrester may help. Further, raising the crest and flattening the side slopes of embankment (to the tune of 0.6 m. or so), wherever required and strengthening the side slopes by bamboo pin reinforcement may also be considered as the palliative measure.

But all these adhoc measures may not ensure total safety of the human habitation. The creation of a second line of defence, in the form of circuit embankment in the landward side will offer additional safety of the people in case of breaching of the frontal embankment (Fig. 20). Further, this will allow sediment dispersal away from the river bed. The area lying in between must be used for creating a vegetative shield. Special care is recommended for right bank embankments as the easterly wind (or *Puber Haoa* as described by local people) does not get any resistance while crossing a wide creek and creates turbulent wave. This is the reason of the vulnerability of the east-facing embankment built along right bank. The Technical Committee Experts (CTE) constituted by Irrigation and Waterways Department submitted its report in March 2021. The committee relied exclusively on civil engineering and made several important recommendations to rebuild/ repair damaged embankment. The borrowing soil was an important issue. The suggestions are reproduced here as reference:

Fig. 20 The proposed retired embankment as second line of defence.

1. *Excavating borrow pits on the countryside to collect soil for reconstruction of Embankments is strongly discouraged and required materials may be sourced from:*

(A) *River side berm land, subject to leaving a gap of at least 15m. from river slope of the reconstructed embankment and restricting the depth of the borrow pit to 1.5m.*

(B) *Charlands in river bed or wide Sea beach provided;*

i. *Such Charlands are at least 500 m. away from the centerline of the existing bridges and Jetties.*

ii. *For river Char land, the extraction zone should be in the central one-third of the river bed or at least 100 m. away from the existing bank line, whichever is less.*

iii. *Depth of the extraction should not exceed 3m. below lowest tide level during season of work.*

2. *Since soil materials collected thus, would be in wet condition, mechanical compaction of the embankment section after laying at or near 'Optimum Moisture Content' (OMC) may not be required separately. Natural Compaction taking place due to movement of machineries would be sufficient. Moreover, considering that soil is basically cohesive in nature as revealed from geotechnical investigations, there will be long-term consolidation over the passage of time.*
3. *In the zone of active erosion, the length of working zone for undertaking anti-erosion measures may be the length of reconstruction of embankment plus 30 m on either side. The entire operation of the reconstruction of embankments in these stretches may be carried out in two working seasons. In the first season, the porcupine cages and spurs should be placed in position as per drawing, starting from toe-line of the existing embankment, without disturbing it. In the next season, when some deposition would take place at this dumping zone, reconstruction of embankment and other related works may be taken up as per drawing.*

But the armoured or concretized embankment, be it along the river bank or the sea-front, cannot prevent overtopping of the swelling water. In all vulnerable stretches, a second line of defence in the form of circuit/parallel embankment is absolutely essential and should be treated as a priority project to ensure the safety of the people. The alignment of second embankment may be in compliance with CRZ notification (2019) which states 50 metres on the landward side from HTL of any tidally active river or width of the creek whichever is less should be declared 'no construction zone'.

We should allow the rivers to widen during high tide as far as possible to facilitate deposition of sediment load on the inter-tidal space. A parallel embankment along the landward limit of high tide will ensure freedom from flood. The area lying between old and new embankment may be used for plantation. The soil may be borrowed creating ponds or water bodies. The rejuvenation of moribund channels may serve the dual purposes of rain water harvesting and excavated earthen materials may be used for embankment building. Since decayed channels are owned by the Government, issue of land acquisition will not hamper the project. Further, it will also guarantee rural employment. The fresh water accumulated therein will change the face of rural economy. As the aquifer in Sundarban is found more than 360 m. below ground level and only one crop is produced in farmland, the rain water harvesting will facilitate multiple cropping. The benefits of such work will percolate down to the poor villagers. Apart from re-excavation of moribund channels, the river beds of embanked channels which have experienced uninterrupted sedimentation during last two centuries and lost their water-holding capacity substantially, may also be dredged and sediment thus collected may be used for restoration/building of the embankment. The mechanical dredger similar to that used by Kolkata Port Trust to resuscitate the navigation channel may be deployed in Sundarban. One of the reasons of frequent submergence of Sundarban is the very low height of land above mean sea level. We may adopt a pilot project to elevate low-lying areas in a selected island transferring sediment load from river to land in the same way the Bidhannagar (erstwhile Salt Lake City) was reclaimed from a swamp in 1960s. The elevated areas may be used to render safe home to the flood victims.

Encroaching Coastline and Shrinking Islands

Along 120 km.-long east-facing coast of East Medinipur between the Subarnarekha and the Rupnarayan, the easterly wind dragged swelling water and marooned large areas on 26 May 2021. The coastline of West Bengal is fast eroding and the Sea is encroaching inland. The comparison of multi-temporal maps and satellite images, on a GIS platform clearly reveals that the coast of West Bengal is retrograding, meaning shifting inland (Rudra, 2018, 2021). Whether littoral front will prograde towards the Sea or retrograde landward depends on the critical balance between amount of sediment supply carried by the rivers and rate of sea level rise. The following tables reveal that all coastal islands of West Bengal have been reduced in size during the period 1970 to 2020 (Hazra, 2021).

Table 4: Shrinking inhabited islands

Islands	Area in km^2 in different years					
	1970	2000	2005	2010	2015	2020
G-Plot	52.31	42.06	41.54	41.49	41.32	40.79
Sagar	250.66	240.02	238.78	237.55	237.19	233.40
Namkhana	151.61	144.83	144.80	143.93	144.85	143.79
Moushuni	33.51	28.92	28.39	27.53	27.30	26.21
Ghoramara	8.59	5.26	4.87	4.45	4.23	3.59

Table 5: Shrinking mangrove islands

Islands	Area in km^2 in different years					
	1970	2000	2005	2010	2015	2020
Dhanchi	38.73	36.08	34.57	34.18	34.03	33.14
Dalhousie	79.22	67.10	65.82	62.20	61.05	57.11
Bulchery	32.81	26.91	25.27	23.28	21.77	19.23
Bangaduni	45.49	31.31	29.55	26.15	23.82	20.98
Jambudwip	17.74	5.39	5.19	4.43	4.20	3.05

It is observed that 129 km^2 land have been eroded from the sea-front in preceding five decades, while 90 km^2 new char has emerged due to decay of tidal channels. It is important to observe that even five mangrove-covered islands have been reduced in size due to wave attack. While five inhabited islands lost about 49km^2 land, five forest-covered islands lost more than 80 km^2 land. It is surprising to note that mangrove islands are eroding at a faster rate than the inhabited islands (Figs. 21-30). This means vegetative wall may not fully resist the invading Sea-wave. But properly designed green wall coupled with strongly built armoured dyke and artificial offshore wave breaker may resist the encroaching Sea.

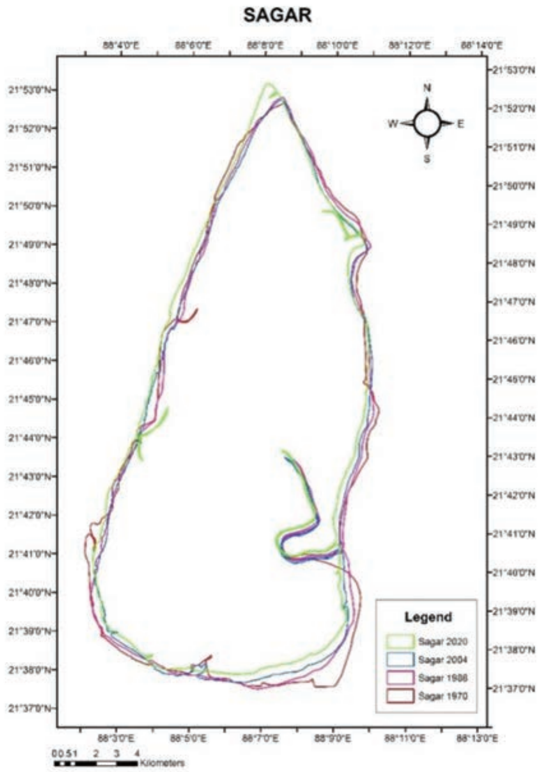


Fig. 21

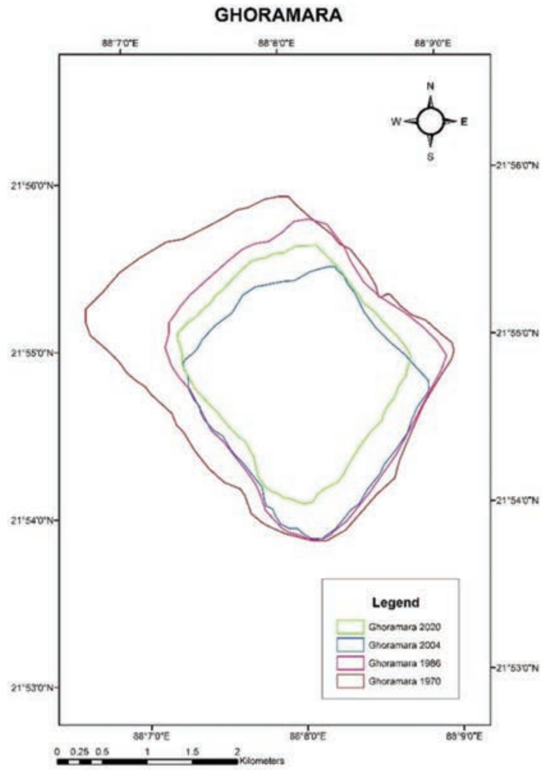


Fig. 22

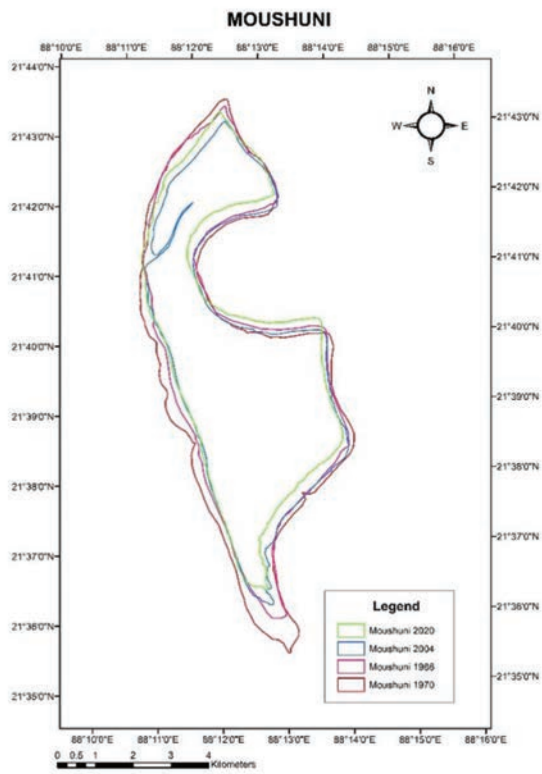


Fig. 23

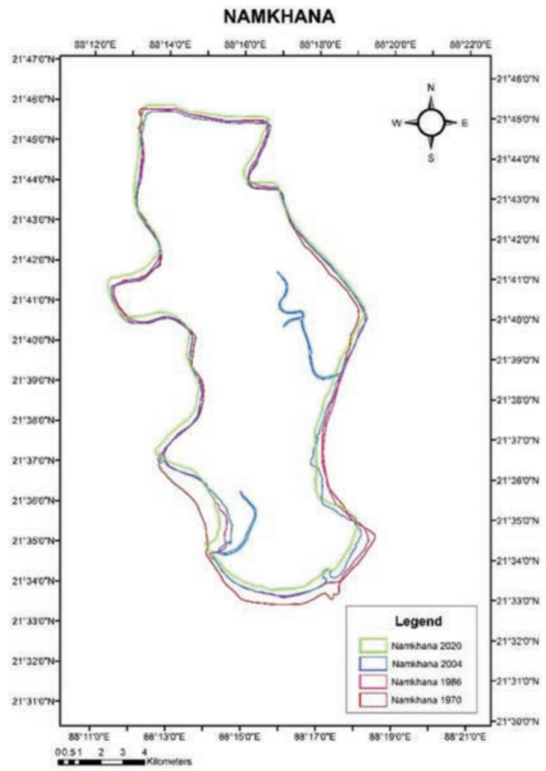


Fig. 24

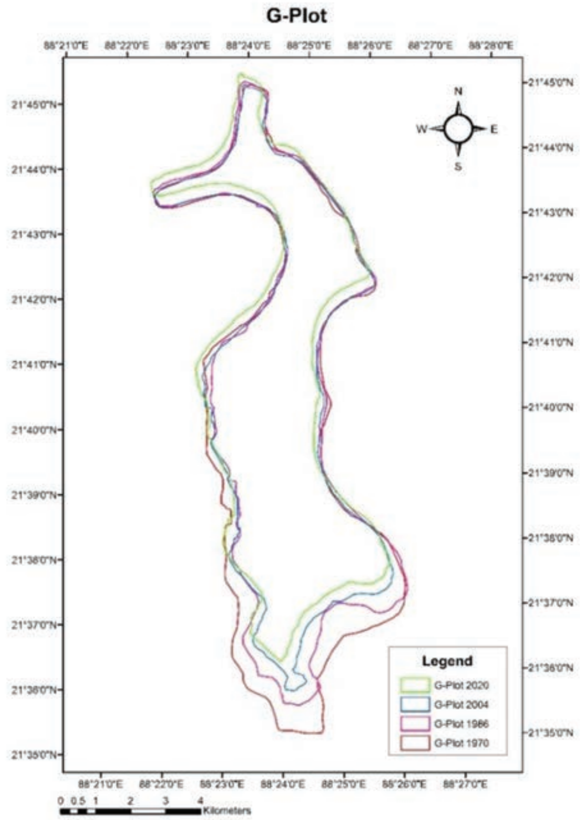

G-Plot
Legend
G-Plot 2020
G-Plot 2004
G-Plot 1986
G-Plot 1970
N
S
E
W
Kilometers

Fig. 25

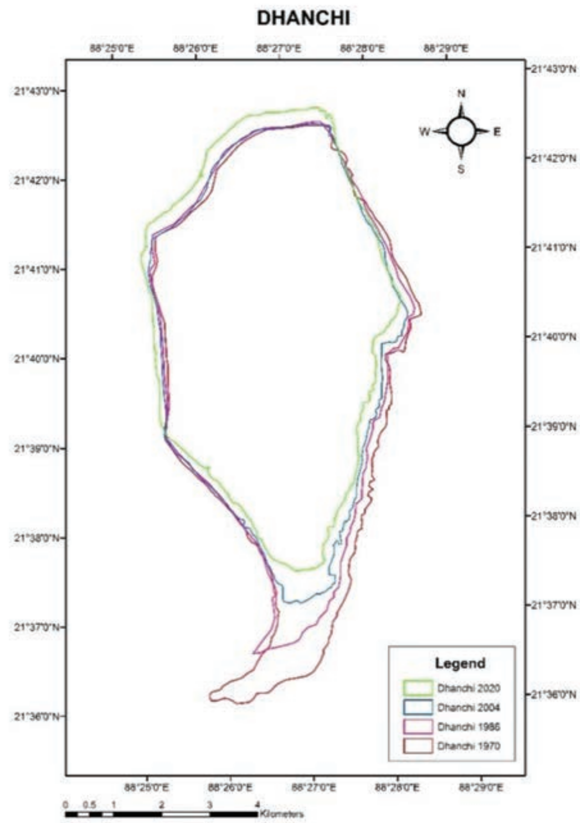

DHANCHI
Legend
Dhanchi 2020
Dhanchi 2004
Dhanchi 1986
Dhanchi 1970
N
S
E
W
Kilometers

Fig. 26

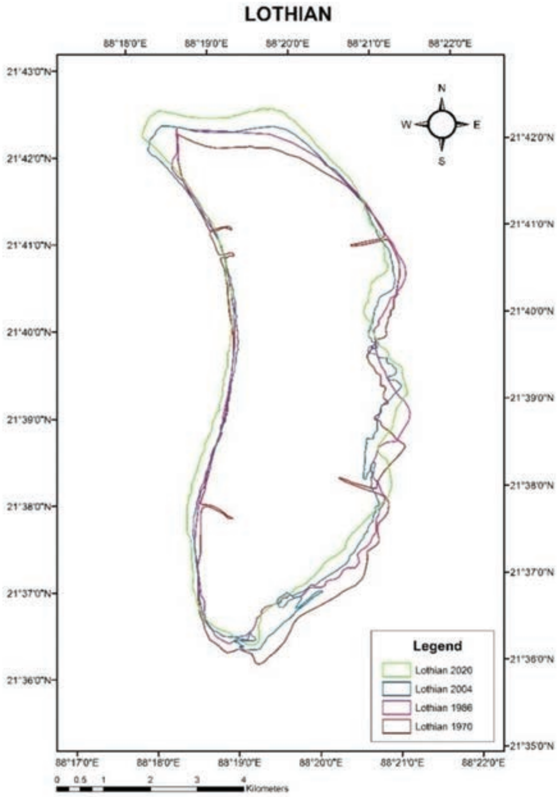


Fig. 27

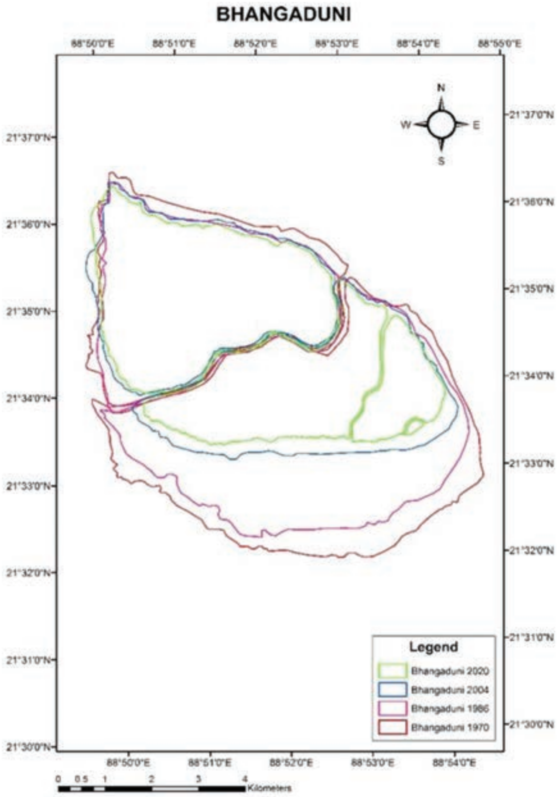


Fig. 28

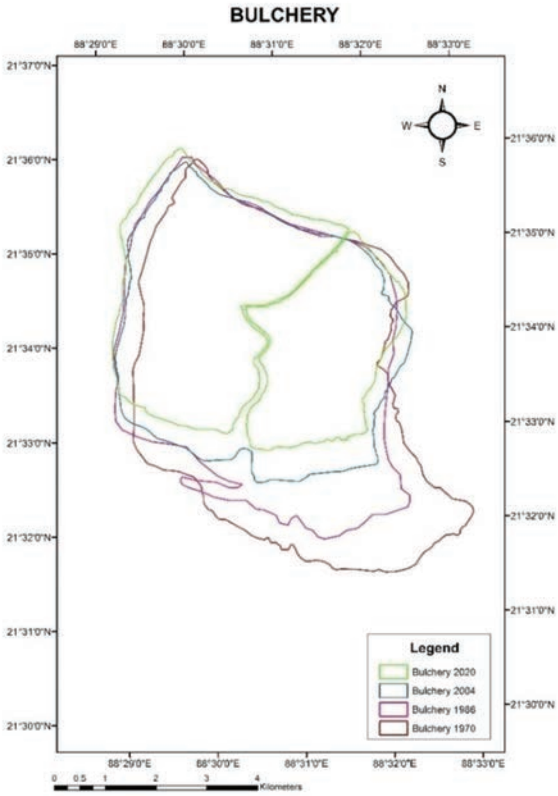


Fig. 29

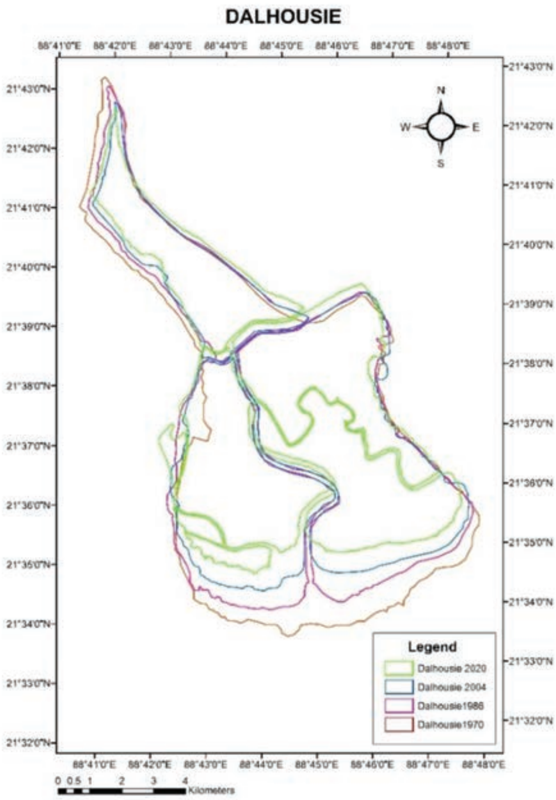


Fig. 30

Sea-Facing Dykes

In this scenario of changing climate, it impossible to resist the aggression of sea-wave only by cresting a bio-shield. The mangroves cannot germinate and hold ground in open, eroding sections of the coast. Mangrove plantation in these localities would not be able to reverse the erosion, it will only work in protected, enclosed sections or where the offshore gradient is gentle (Bandyopadhyay, 2021). In the 30km.long sea-front of four inhabited islands (Sagar, Moushuni, Bakkhali-Namkhana and G-plot), reinforcement of the existing embankments with concrete and their protection with thoughtfully planned vegetative buffers should work well to prevent overtopping of storm surges. Therefore, the coasts need to be classified first for their suitability for available options. In erosional and exposed localities, it is also important to put two parallel dykes with cross-embankments put at regular intervals between them to prevent widespread flooding of the interiors in the events of beaching or wave-overtopping of the outer embankments. If the frontal old embankment is located along the High Tide Line (HTL), the buffer area between the old and new dykes may ideally be 200 m. and should be declared as ‘no construction zone’ in compliance with the Coastal Zone Regulation (2019) (Fig.31).

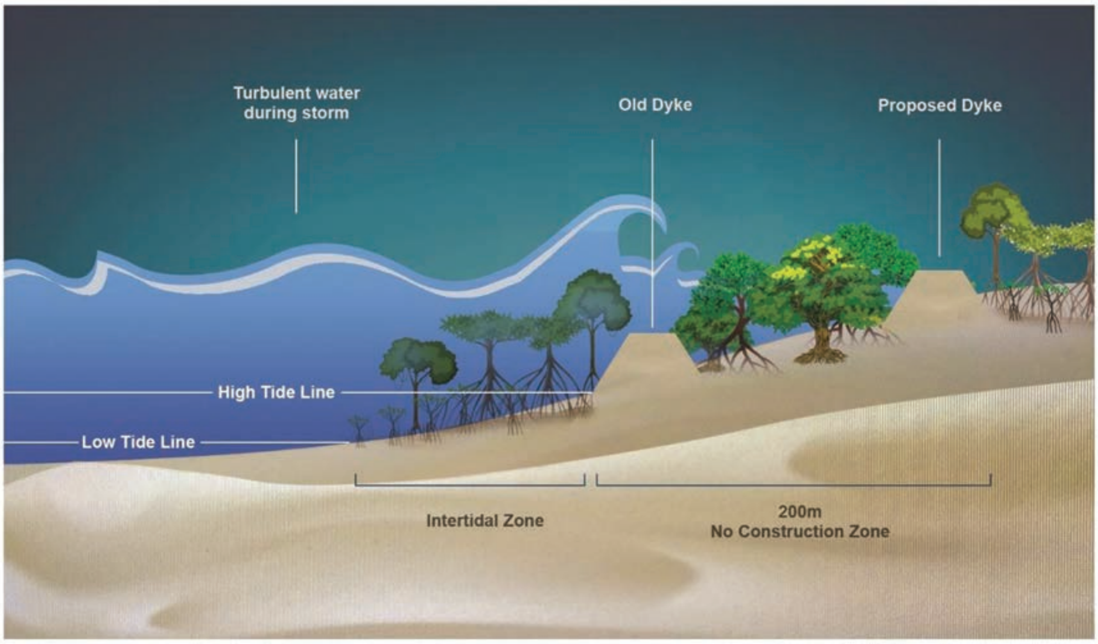


Fig. 31 Proposed parallel dykes along the coast

The suggested floral species may be planted in space trapped in between the parallel dykes. However, as a quick analysis from remote sensing studies of Sagar, and Moushuni islands reveals, such an implementation may necessitate the relocation and rehabilitation of 630 households in Sagar, and 605 households in Moushuni. For the entire Sundarban area, the number of households to be relocated would be higher and may be determined through rigorous mapping exercises (Hazra, 2021). The proposal of IIT-Madras for constructing 2.30

km.-long reef barrier off the southern front of the Gangasgar island is under consideration of the Government of West Bengal. It will be placed 150-200 m. away from the LTL at a depth of 2.30 m. It will act as wave breaker and reduce intensity of erosion (See Fig. 32). This is proposed as a pilot project and if found to work well, it would be replicated elsewhere. But the southern sea-front of Sagar Island has a length of 14 km. The short off-shore barrier may lead to increasing erosion at both ends of the barrier. We propose on-shore protection of sea-front at both sides of the off-shore barrier.

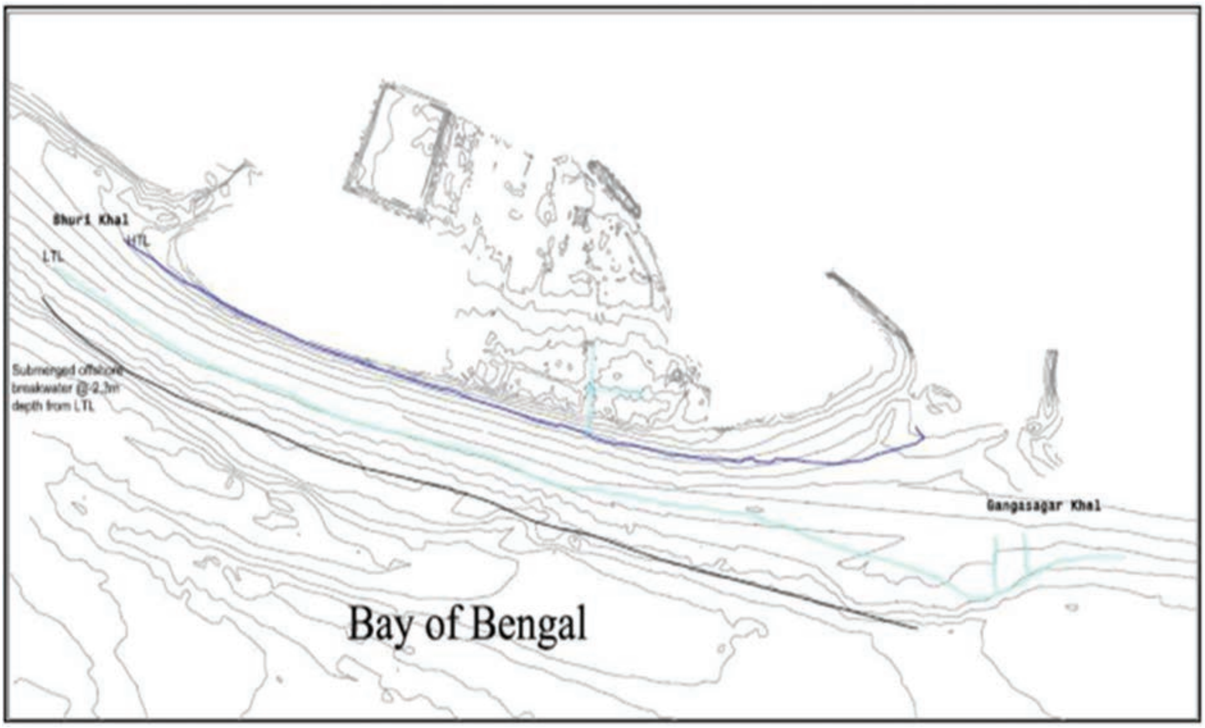


Fig. 32 Proposed offshore reef barrier away from the Gangasagar, proposed by IIT Madras

Vegetative Protection of Embankment

The Committee explored the vegetative solution of the problem of recurrent breaches in the embankment of Sundarban. The five successive layers of vegetations, three in frontal zones (A, B, C) and two in landward side (D, E) were planned to reinforce embankment with pre-seeded bio-geotextile (Mukherjee and Sen Sarkar, 2021; Fig. 33). A template was provided to all experts and they submitted their reports accordingly. After compilation of the reports, it is revealed that the experts have suggested 29 varieties for Zone A, 44 for B, 51 for C, 45 for D and 42 for E. After careful consideration sand-silt-clay ratio, salinity, pH, and ability of the plant to hold soil as well as to absorb storm-thrust, we propose following species which are mostly indigenous to the Sundarban. While selecting the floral species, we subdivided the riverine embankments into four groups based on their alignments. These are- a) east-facing, b) west facing, c) south-facing; d) north facing. Accordingly,10 species are recommended for zone A, 15 for B, 9 for C, 4 for D, and 7 for E zone. In case of sea-facing embankment, 7 different species were chosen for frontal beach and 3 for landward side with an armoured embankment in between. A forest-wall may be created in between two parallel dykes (See Fig. 33). Further, the long east facing coast of East Medinipur had been worst sufferer due to the Yaas. Considering international best practices, we propose create a three-layer forest wall. Since dune plays very important role, having ability to replenish the beach, vegetative protection of the coastal tract of East Medinipur is also planned.

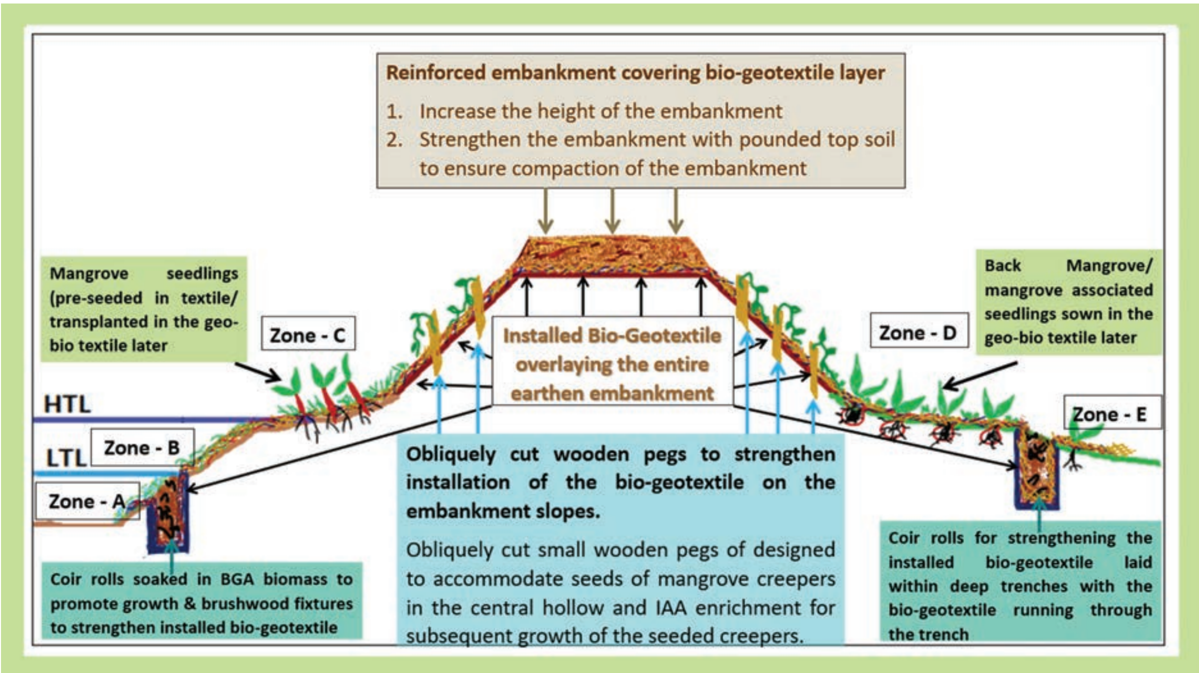


Fig. 33 Schematic diagram showing suggestive vegetative protection.

Table 6: The ecological principles of selecting the species.
1. **Emphasis given on using multi-species plantation programme.** Proposal includes suggestions of mangroves, mangrove associates, back mangroves, beach flora, mangrove grasses and the indigenous algae ~35 different species, keeping in mind the natural rich species diversity of the region. Ecologically speaking, the ecosystem promotes rich diversity and can be sustained too by the same.
2. **Species variations suggested for different positions and faces of the embankments in accordance with inherent soil and physical attributes of the sites.** Such variations depend on forest face and position of embankments in terms of site-specific species preferences observed over the years. These are further regulated synergistically by sand:silt:clay ratio, tidal influence, variations in salinity, sediment load shifts, wave action, wind force, human activities, and many others, most of which are beyond our control. But the ecosystem's support for natural regeneration is regulated by numerous factors, so discrete choice of site-specific species combinations is important for the success of any plantation programme in this region. Specificity can further be increased for certain site-specific needs during plantation.
3. **Follows inherent pattern of vegetation succession of Sundarban.** Chronology in planning species structure for plantation has been suggested for different heights and positions of the river embankments following natural vegetation pattern. Succession pattern is initiated in the Sundarban by the blue-green algae and the green algae which consolidate the ill-consolidated soil paving way for the floating propagules of mangrove species like *Avicennia* spp., *Sonneratia* sp., and others to gain ground on this tide washed lands and establish themselves. The same pattern when followed in the plantation programme will expedite the succession pattern.
4. **Promotes enhanced mangrove regeneration rate both naturally and through human intervention (people's participation) by means of providing alternate livelihood option.** The requirement of multi-species nursery raised mangrove seedlings/ mangrove grass turfs/ mangrove propagules/ biomass of mangrove algae (green and blue-green) shall ensure that the mangrove propagules are not wasted as fuel by the fringe area population and also provide another livelihood option for the locals in nurturing multi-species nurseries. This shall contribute to enhancing mangrove regeneration rate both naturally and through local intervention.

The effectiveness of the proposed green technological intervention in terms of multi-species plantation for providing vegetative solutions to embankment stability, crucially hinges on the social acceptability and community involvement in the project. Since the forest department is majorly involved in nursery raising of propagules collected from the ecosystem, and many of the species suggested in the report would be more adapted to other measures of nursery raising, the creation of such a multi-species nursery needs to be taken up as an extensively large-scale endeavour by the local people in definite terms. This will require capacity building in terms of nursery raising of multi-species propagule material all the year through. Furthermore, preserving the mangrove plantation and ensuring its long run sustenance can be achieved either through surveillance or integrating community livelihood with project. Enforcement involves monitoring cost and it might also be detrimental towards integration of the community in the plantation project. As an alternative, the benefits that might accrue to the habitants from the mangrove plantation over time need to be estimated. Thus, exploring the possibility of whether this embankment mangrove plantation can be sustained as a common property resource is an important aspect of sustaining this as a long-term robust solution. Community organizations like self-help groups and even the fringe area population *per se* can be involved in nursery creation and managing the mangrove plantation as an alternate livelihood option.

Table 7: Multi-layer floral species recommended to protect the embankment in Sundarban.

	Zone A	Zone B	Zone C	Zone D	Zone E
Riverine Embankment (East facing)	**Blue-Green algae mixture#**	***Avicennia alba***	***Sonneratia apetala***	***Avicennia officinalis***	***Cynometra ramiflora***
	Green algae*	***Avicennia marina***	***Excoecaria agallocha***	***Xylocarpus granatum***	***Thespesia populnea***
	Porteresia coarctata	***Ceriops decandra***	***Bruguiera gymnorhiza***	***Xylocarpus moluccensis***	***Thespesia populneoides***
	Avicennia alba*	***Kandelia candel***	***Rhizophora mucronata***	***Heritiera fomes***	***Hibiscus tiliaceous***
	Avicennia marina*	***Aegiceras corniculatum***	***Aegiceras corniculatum***	***Brownlowia tersa***	
	Acanthus ilicifolius*	***Acanthus ilicifolius***	***Aegialitis rotundifolia***		
	Most of the highly vulnerable embankments have been identified as East facing concave banks. Due to their degenerative nature and probable non availability of proper plantation sites, it is imperative that immediate structural measures be taken to facilitate sediment accretion and create barrier strategies in addition to the suggested plantation species. These measures may be planned so as to remain stable till the suggested plantation takes over the role of being a vegetative barrier. These areas should also be left with some freedom for riverine dynamics to act upon so as to let the landmass grow on its own.				
Riverine Embankment (West facing)	**Blue-Green algae mixture**	***Avicennia alba***	***Sonneratia apetala***	***Avicennia officinalis***	***Cynometra ramiflora***
	Green algae*	***Avicennia marina***	***Excoecaria agallocha***	***Xylocarpus granatum***	***Thespesia populnea***
	Porteresia coarctata	***Ceriops decandra***	***Bruguiera gymnorhiza***	***Xylocarpus moluccensis***	***Thespesia populneoides***
	Myriostachya wightiana	***Aegiceras corniculatum***	***Rhizophora mucronata***	***Heritiera fomes***	***Hibiscus tiliaceous***
	Salicornia brachiata	***Acanthus ilicifolius***	***Aegiceras corniculatum***	***Brownlowia tersa***	
	Avicennia alba*	***Clerodendrum inerme***	***Aegialitis rotundifolia***		
	Avicennia marina*		***Clerodendrum inerme***		
	Acanthus ilicifolius*				
Sea facing Embankment	**OFFSHORE BARRIER**	***Scyphiphora hydrophyllacea***	**ONSHORE PARALLEL EMBANKMENT WITH VEGETATIVE SHIELD IN BETWEEN**		***Cocos nucifera***
		Rhizophora apiculata			***Phoenix sylvestris***
		Lumnitzera racemosa			***Borassus flabellifer***
		***Pandanus* sp.**			
		Ipomoea pes-caprae			
		Spinifex littoreus			
		Opuntia dilleni			

Table 7: Multi-layer floral species (Continued)

	Zone A	Zone B	Zone C	Zone D	Zone E
Riverine Embankment (South Facing)	**Blue-Green algae mixture**	***Avicennia alba***	***Sonneratia apetala***	***Xylocarpus granatum***	***Cynometra ramiflora***
	Green algae*	***Avicennia marina***	***Excoecaria agallocha***	***Xylocarpus moluccensis***	***Thespesia populnea***
	Porteresia coarctata	***Ceriops decandra***	***Bruguiera gymnorhiza***	***Heritiera fomes***	***Thespesia populneoides***
	Myriostachya wightiana	***Aegiceras corniculatum***	***Rhizophora mucronata***	***Brownlowia tersa***	***Hibiscus tiliaceous***
	Avicennia alba**	***Acanthus ilicifolius***	***Aegialitis rotundifolia***		
	Avicennia marina**	***Sesuvium portulacastrum***	***Clerodendrum inerme***		
Riverine Embankment (North Facing)	***Porteresia coarctata***	***Avicennia alba***	***Avicennia officinalis***	***Xylocarpus granatum***	***Cocos nucifera***
	Myriostachya wightiana	***Avicennia marina***	***Avicennia alba***	***Xylocarpus moluccensis***	***Phoenix sylvestris***
	Avicennia alba	***Bruguiera gymnorhiza***	***Avicennia marina***	***Heritiera fomes***	***Borassus flabellifer***
	Avicennia marina	***Ceriops decandra***	***Sonneratia caseolaris***	***Brownlowia tersa***	
	Suaeda nudiflora		***Bruguiera gymnorhiza***		
	Vetiveria zizanoides***				

NOTES:

Blue-Green algae (*Neel Sobuj Sheola*) can only be applied if sufficient land is available for triggering natural succession process.
***Green algae (*Sobuj Sheola*) shall constitute vegetative filaments of primarily *Rhizoclonium* and *Chaetomorpha* collected from the forest floors of Sundarban.**
**** Plantation of these species should be taken up only when the soil in Zone – A consolidates significantly**
***** Introduction of *Vetiveria zizanoides* has to be very carefully undertaken in this vulnerable ecosystem, ensuring that it has no scope or trend to become invasive at any point of time.**

Table 8: Common / vernacular names of suggested species

Scientific name	Local name	Scientific name	Local name
(Major & Minor Mangroves; Mangrove Associates)		**(Mangrove grasses; Back Mangroves; Beach flora)**	
Avicennia alba	Kaal baine	***Porteresia coarctata***	Dhani ghaash
Avicennia marina	Peyara baine	***Myriostachya wightiana***	Naal ghaash
Avicennia officinalis	Jaat baine	***Spinifex littoreus***	
Bruguiera gymnorhiza	Kankra	***Clerodendrum inerme***	Bon Jui
Ceriops decandra	Jhamti goran	***Sesuvium portulacastrum***	Jodu palong
Ceriops tagal	Moth goran	***Vetiveria zizanoides***	Vetiver
Rhizophora mucronata	Garjan	***Salicornia brachiata***	Nona shaak
Rhizophora apiculata	Bhaara	***Hydrophyllax maritima***	
Sonneratia apetala	Keora	***Ipomoea pes-caprae***	Chagol Kuri
Sonneratia caseolaris	Keora/ Ora	***Suaeda nudiflora***	Giria shaak
Excoecaria agallocha	Geona	***Pandanus* sp.**	Keya
Aegialitis rotundifolia	Tora	***Cynometra ramiflora***	Singaar
Aegiceras corniculatum	Khalsi	***Thespesia populnea***	Porosh
Xylocarpus granatum	Dhudul	***Thespesia populneoides***	Boro Porosh
Xylocarpus moluccensis	Pasoor	***Hibiscus tiliaceous***	Bhola
Heritiera fomes	Sundari	***Opuntia dilleni***	Phani mansa
Scyphiphora hydrophyllacea	Tagribani	***Cocos nucifera***	Narkol
Lumnitzera racemosa	Kripa	***Phoenix sylvestris***	Khejur
Brownlowia tersa	Lata sundari	***Borassus flabellifer***	Taal
Acanthus ilicifolius	Harkoch kata		

Coastal tract of Purba Medinipur

The 41 km.-long coastal stretch of Purba Medinipur from the Subarnarekha mouth to Pichhabani inlet is the major hub of coastal tourism. This stretch is also an important fishing harbour. This long stretch has been drastically modified and heavily engineered in places. In the virgin coast, the sand dunes are integral part of the beach and there is reciprocal relationship of to and fro sand movement between the two segments. Both the dune and the beach replenish each other. But in the stretch between New Digha to Ramnagar, a leaner concrete embankment has disconnected the beach from the dune. While beach has been continuously eroded and lowered by wave erosion, its nourishment through movement of sand from the dune is interrupted by the presence of an intervening dyke. Both the dune and the beach at Mandarmani have been flattened by the Hoteliers violating CRZ regulation. Many hotels are found either within inter-tidal space or in 'no construction zone' as per CRZ guideline of 2019. We need to be careful for Shankarpur-Tajpur area which is not yet much modified by the human intervention.

Shifting shoreline:

The coastline of Purba Medinipur has been encroaching inland. Chaudhuri (2021) has studied the shifting of shoreline both spatially and temporally based on multi-temporal satellite images of the period between 1995 to 2021. The landward shifting of the coastline in the period under consideration was studied based on the position of highest high tide line (HHTL) which has shifted more than three m/year at Gangadharpur, Tajpur, Mandarmani and Talsari. The shoreline has been made static by the Dyke at Old Digha. The rate of shoreline change has been accelerated since 2019 in the non-protected stretch due to aggression of the three successive cyclones namely Bulbul, Amphan and Yaas. To appreciate the changes during last five decades, we compared the shoreline as it was in 1972 with that of 2021 at New Digha, Old Digha, Shankarpur and Tajpur, and found that the sea has encroached 121 m, 276 m, 315 m and 294 m respectively (Figs. 34-37). Thus it is revealed that the Sea has been encroaching inland at an average rate of five m/year along the Purba Medinipur coast. The high wave generated during the storm erode the upper beaches leading to its lowering. But in a virgin or non-protected beach its lowering and landward retreat of dune-cliff are complimentary. The seaward movement of sands from retreating cliff accretes the beach and thus maintains the profile of equilibrium. The construction of dyke has stopped the landward expansion of the beach but accelerated its lowering (Figs. 38-41). The beach lowering and sea level rise together alter the geomorphic process. The relatively narrow and lowered beach lost its ability of dissipating wave energy and consequently the turbulent Sea during the cyclone easily overtopped the dykes and damaged properties on 26 May 2021 at Digha and adjoining coast. The alarming beach lowering ultimately endangers the dyke and leads to its collapse. Further, as the beach lowered and narrowed, simultaneously wave breaker zone came closer and the turbulent Sea tends to attack the coast with vigour at the time of cyclonic invasion. The work of coastal defence need to start from the continental shelf i.e the gently sloping submerged part. To go for it, the underwater topography is to be surveyed bathymetrically and the hydrodynamics should be known with proper instrumentation. This may begin in a selective way, for most vulnerable sections. The time series analysis of satellite images has clearly revealed that the Bay of Bengal has been encroaching inland along entire coast of Purba Medinipur. There are two ways to protect the beach; firstly, a series of protruding groyen may trap the eastward drifting sediments from the Subarnarekha estuary and help to grow new beach; Secondly the installation of an artificial offshore reef-barrier to push back the wave-breaker away from the beach may also be considered and a pilot project may be adopted for an extremely vulnerable stretch. But any such intervention needs prior understanding of the off-shore bathymetry, sediment movement and possible impact on navigation. Such structure is expected to intercept the sediment load washed away from the beach and prevent destruction during storm surge. The Irrigation and Waterways Department is going to undertake a project entitled "Master Plan for shoreline management and coastal protection works in Digha–Shankarpur–Tajpur- Mandarmani area within Ramnagar- I & II Blocks, District Purba Medinipur" and IIT-Madras will be the collaborator in this endeavor.

While there are many examples of natural reef acting as a submerged wave-breaker, successfully performing in shoreline stabilisation and managing the adverse impact of storm and cyclone surges; installation of artificial 'reef ball 'structures in different parts of the northern world are found to be equally advantageous in ecosystem regeneration (Harris, 2006). Such artificial reef structures have been proven to be efficient through experimental and modelling studies in protection and stabilisation of eroding coasts (Kim et al, 2020). In recent times, installation of artificial oyster reef break-water in Kutubdia island of Bangladesh could demonstrate seaward growth of the salt marsh, reduction of erosion by sediment trapping (Choudhry et al, 2019). But those works should not be replicated without detailed study of the West Bengal coast. A groyen protruding 370m.into the Sea at Digha Mohana was built with concrete tetrapod and basaltic boulders in 2009-10. This structure successfully trapped eastward drift of sediment and consequently a new beach has emerged. But this structure had adverse impact on Shankarpur beach which has been deprived of sediment and eroded fast.

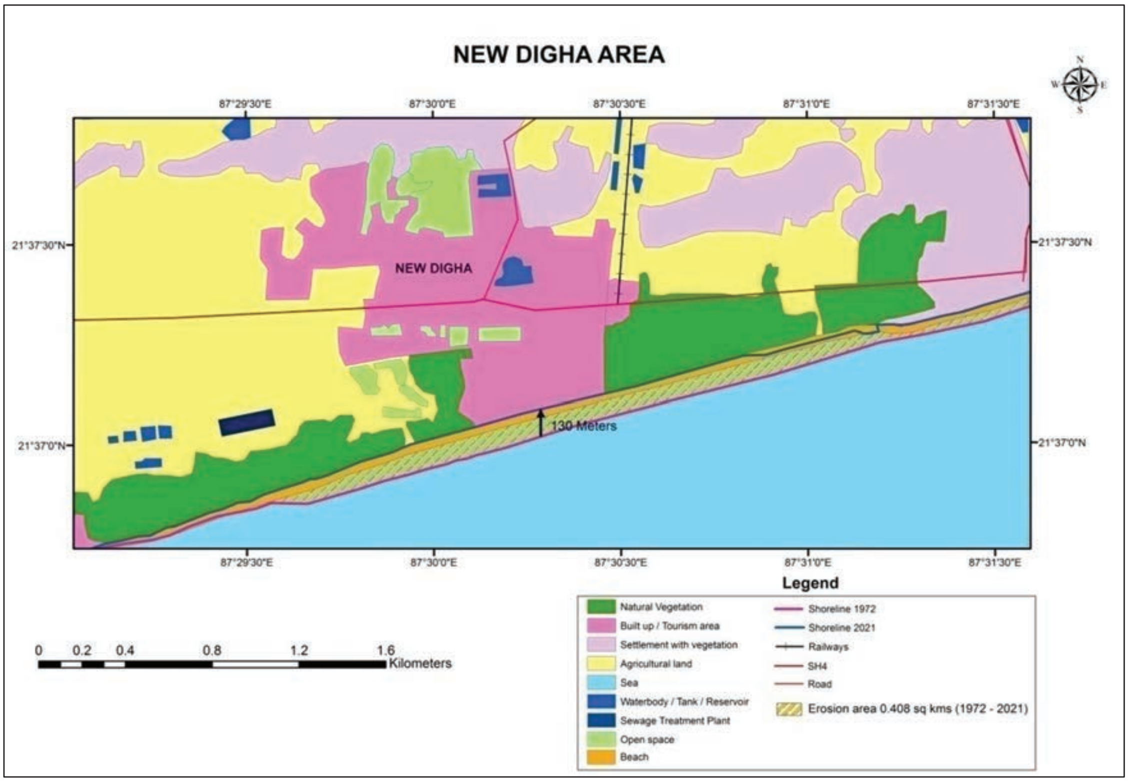

NEW DIGHA AREA
87°29'30"E
87°30'0"E
87°30'30"E
87°31'0"E
87°31'30"E
21°37'30"N
21°37'0"N
NEW DIGHA
130 Meters
Legend
Natural Vegetation
Built up / Tourism area
Settlement with vegetation
Agricultural land
Sea
Waterbody / Tank / Reservoir
Sewage Treatment Plant
Open space
Beach
Shoreline 1972
Shoreline 2021
Railways
SH4
Road
Erosion area 0.408 sq kms (1972 - 2021)
0 0.2 0.4 0.8 1.2 1.6
Kilometers

Fig. 34

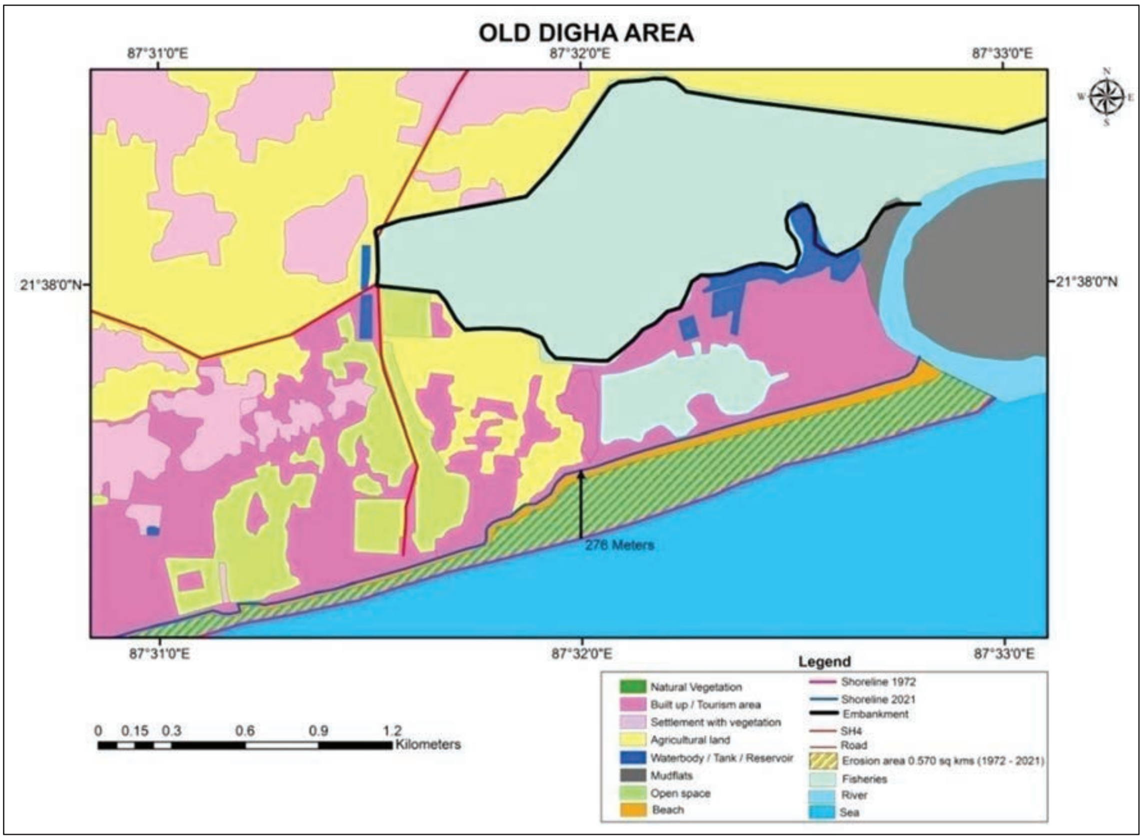

OLD DIGHA AREA
87°31'0"E
87°32'0"E
87°33'0"E
21°38'0"N
276 Meters
Legend
Natural Vegetation
Built up / Tourism area
Settlement with vegetation
Agricultural land
Waterbody / Tank / Reservoir
Mudflats
Open space
Beach
Shoreline 1972
Shoreline 2021
Embankment
SH4
Road
Erosion area 0.570 sq kms (1972 - 2021)
Fisheries
River
Sea
0 0.15 0.3 0.6 0.9 1.2
Kilometers

Fig. 35

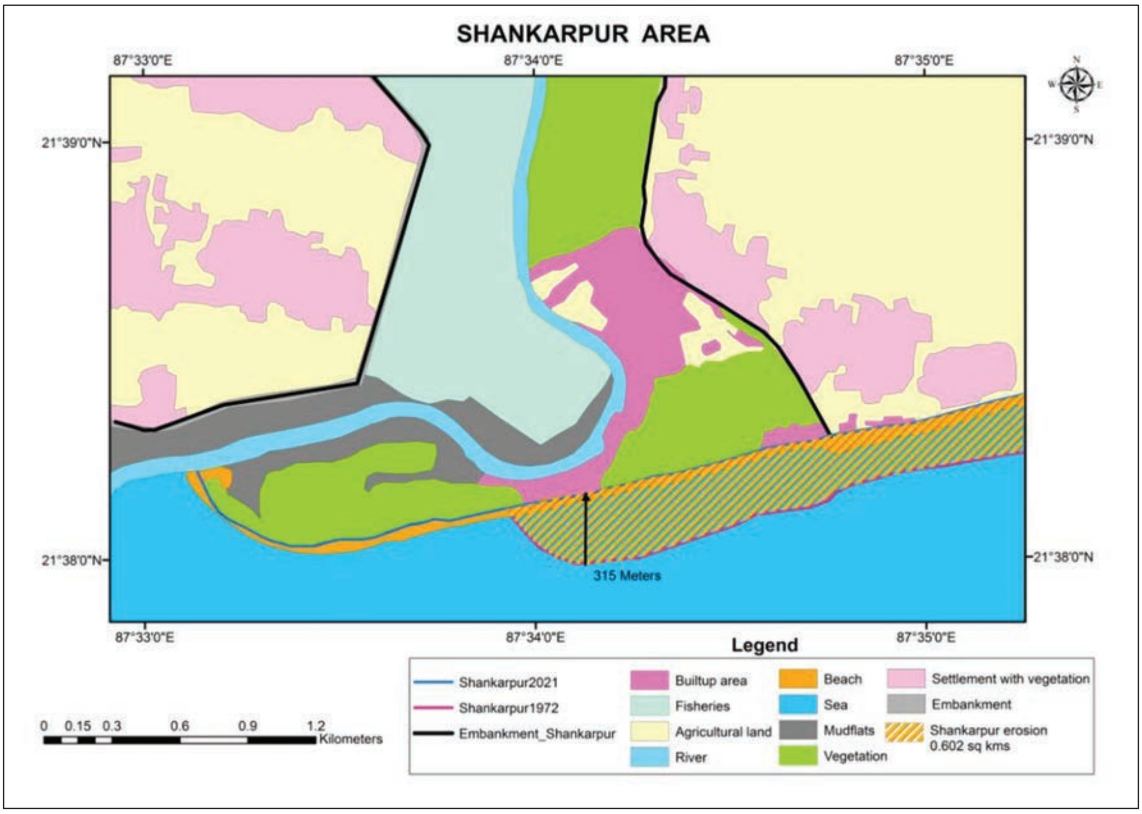

SHANKARPUR AREA
87°33'0"E
87°34'0"E
87°35'0"E
21°39'0"N
21°38'0"N
315 Meters
Legend
Shankarpur2021
Shankarpur1972
Embankment_Shankarpur
Builtup area
Fisheries
Agricultural land
River
Beach
Sea
Mudflats
Vegetation
Settlement with vegetation
Embankment
Shankarpur erosion
0.602 sq kms
0 0.15 0.3 0.6 0.9 1.2
Kilometers

Fig. 36

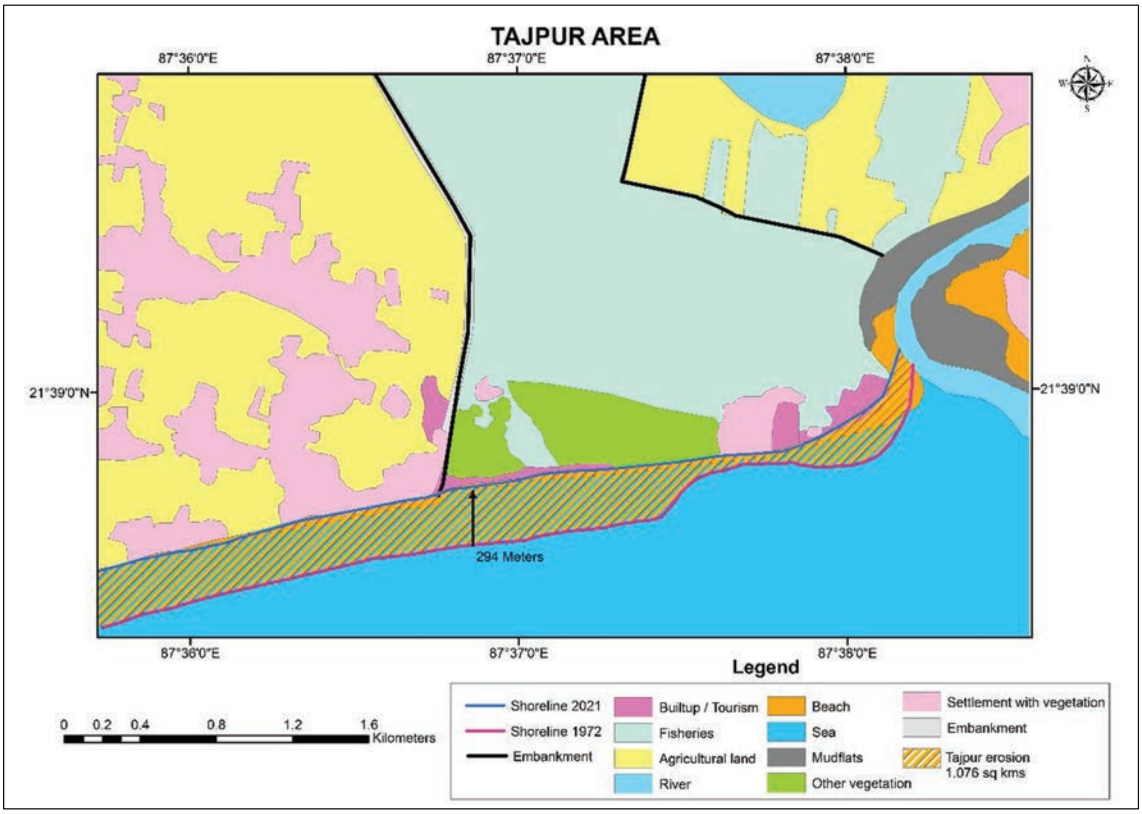

TAJPUR AREA
87°36'0"E
87°37'0"E
87°38'0"E
21°39'0"N
294 Meters
Legend
Shoreline 2021
Shoreline 1972
Embankment
Builtup / Tourism
Fisheries
Agricultural land
River
Beach
Sea
Mudflats
Other vegetation
Settlement with vegetation
Embankment
Tajpur erosion
1.076 sq kms
0 0.2 0.4 0.8 1.2 1.6
Kilometers

Fig. 37

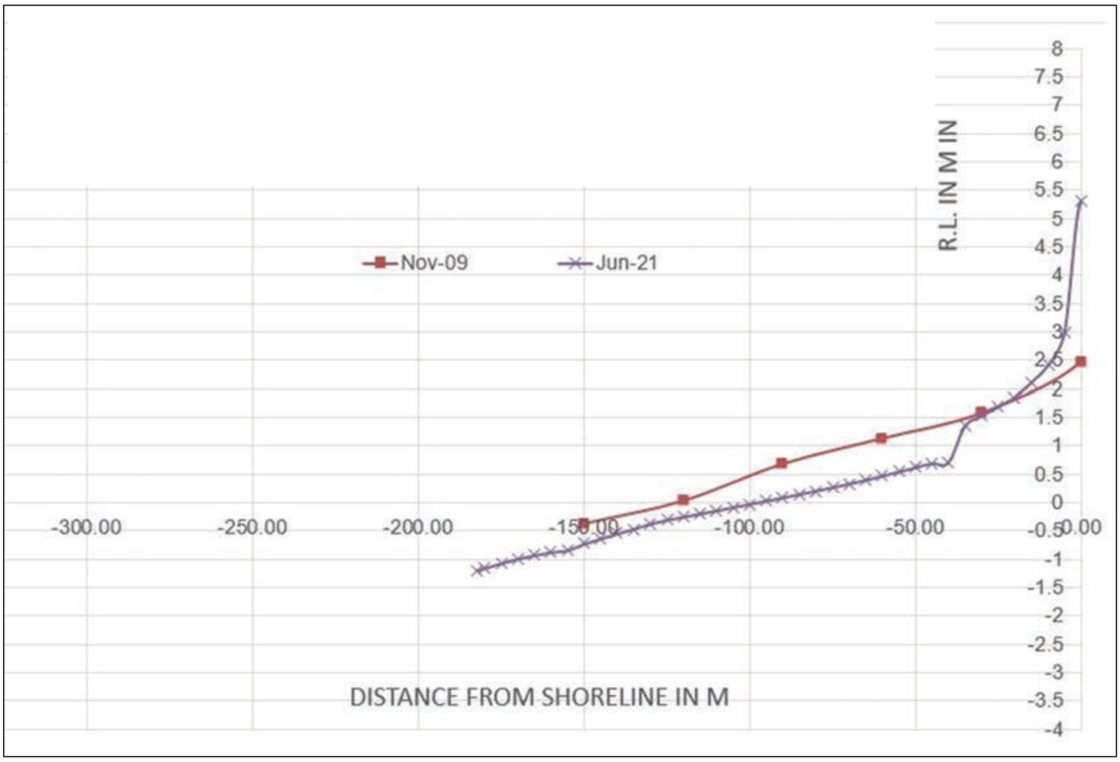


Fig. 38 Lowering of beach between 2009 and 2021

Fig. 39 Exposed tree-root due to beach lowering

Fig. 40 The groyen built in 2009-10 has intercepted off-shore drift of sediment and created new beach

Fig. 41 Engineering intervention with boulders could not resist the encroaching sea

Three-line vegetative barrier:

The Forest Department has already taken initiative to create three-line vegetative barrier along the coastal tract of East Medinipur. An intensified integrated approach will be taken up to plant the Mud flats, Inter tidal Zone and the Sandy coasts of Purba Medinipur District. The local communities will be involved in all stages of plantation, from collection of seeds, planting and maintenance over next 5-10 years. The propagules will be monitored and as and when necessary, nurtured throughout next decade for growing the green cover of mangroves and the Integrated Coastal Shelter Belts thus created. This will generate Man-days for the forest fringe population and at the same time replenish the damaged coastal zones of the district. Three-line barriers will be created. (See Table 9).

SUGGESTIVE MULTI-LAYER FLORAL SPECIES (For Purba Medinipur)

<table>
<tr><th></th><th>Zone 1
(MANGROVE BARRIER)</th><th>Zone 2
(VEGETATIVE BARRIER)</th><th>Zone 3
(COASTAL SHELTER BELT)</th></tr>
<tr><td rowspan="9">Purba Medinipore (Mud flats, Intertidal zones and Sandy coasts)</td><td>Oryza coarctata</td><td>Pandanus sp.</td><td>Pandanus sp.</td></tr>
<tr><td>Avicennia alba</td><td>Vetiveria zizanoides</td><td>Casuarina equisetifolia</td></tr>
<tr><td>Avicennia marina</td><td>Saccharum spontaneum</td><td>Acacia auriculiformis</td></tr>
<tr><td>Avicennia officinalis</td><td>Saccharum munja</td><td>Azadirachta indica</td></tr>
<tr><td>Acanthus ilicifolius</td><td>Arundo donax</td><td>Pongamia pinnata</td></tr>
<tr><td>Excoecaria agallocha</td><td>Ipomoea pes-caprae</td><td>Holoptelea integrifolia</td></tr>
<tr><td>Suaeda nudiflora</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Salicornia brachiata</td></tr>
<tr><td colspan="3">Three-line vegetative barrier will be created
- Zone 1: Mudflats and Intertidal zones and creeks will be intensively planted with viviparous Quality Planting Materials of Mangrove species. The available blanks and recent cyclone damaged Forest land and suitable land (mudflats) will be taken up for this massive Eco-restoration works.
- Zone 2: The bare sand and dunes will be stabilized by planting vegetative barrier and box palisades made of brush wood and different grasses
- Zone 3: The higher areas adjoining the sandy zones will be planted with mixed Coastal Shelter Belt species at 2 m. x 2 m. spacing with a front and end line of Pandanus.</td></tr>
</table>

COMMON/ VERNACULAR NAMES OF SUGGESTED SPECIES

Scientific name	Local name
Oryza coarctata **Synonym *Porteresia coarctata***	Dhani ghaash
Avicennia alba	Kaal baine
Avicennia marina	Peyara baine
Avicennia officinalis	Jaat baine
Bruguiera gymnorhiza	Kankra
Excoecaria agallocha	Geona
Vetiveria zizanoides	Vetiver
Salicornia brachiata	Nona shaak
Acanthus ilicifolius	Harkoch kata
Ipomoea pes-caprae	Chagol Kuri
Suaeda nudiflora	Giria shaak
***Pandanus* sp.**	Keya
Saccharum spontaneum	Kaash
Saccharum munja	Swar ghaash
Arundo donax	Nal ghaash
Pongamia pinnata	Karanja
Acacia auriculiformis	Akashmoni
Azadirachta indica	Neem
Casuarina equisetifolia	Casuarina
Holoptelea integrifolia	Challa

International Best Practices in adopting vegetative Solution for protection of embankments:

After the massive Indian Ocean Tsunami of 2004, an international technical workshop titled 'Coastal protection in the aftermath of the Indian Ocean Tsunami: What role for forests and trees' organised by the Food and Agriculture Organisation (FAO) of the United Nations arrived at several conclusions, which are extremely important in our context (Bratz et al., 2006). Following are the excerpts from the FAO publication:

1. Coastal forests and trees can, under certain conditions, act as bio-shields to protect lives and valuable assets against coastal hazards including tsunamis, cyclones, salt spray and coastal erosion.
2. Care may be taken to avoid making generalisations about the protective role of the forests and trees based on evidence from one or a few areas; the many factors that influence the protective role of the forests/trees must be understood and taken into consideration before lessons can be learned and applied elsewhere.
3. Coastal forests and trees are not able to provide effective protection against all hazards; provision for other forms of protection and evacuation must be relied upon. Care must be taken not to create a false sense of protection against coastal hazards.
4. The options of protection include: soft and hard solutions and a hybrid of the two. If none of these is appropriate and viable, it may be necessary to regulate coastal land use and prevent further settlement and construction of valuable assets in the vulnerable zone. The CRZ regulation (2019) needs to be strictly adhered.

Japan, after the Tohoku Earthquake of 11 March 2011, initiated a project called the 'Great Forest Wall'. The concept is based upon the ideas of Professor Akira Miyawaki, a vegetation ecologist active across the globe with his philosophy of forest restoration/ creation by following the principle of 'potential natural vegetation' and a method known as 'Miyawaki method' of forest creation. The idea was to use sustainable forest as a buffer against any future tsunami. It is expected that the tree-wall will cut the power of tsunamis by 50% and reduce damages. They proposed planting of 90 million trees and extending the great wall for 300 km. and building a five-meter-high embankment from soil and debris of the earthquake and then planting evergreen broad-leaf trees indigenous to the area to create a 'lifeguarding forest.

By using similar method, the Japanese Foundation took up another project, 'Morino' in a quaint and quintessential Japanese beach town of Iwnuma on the Sendai coast where they have developed several models like 'mountains for evacuation', 'private woods for each building', 'breakwaters made of forests' and 'tidal embankments made of forests in coastal areas'. The planted trees would strike deep roots ranging from 4 to 6 meters and in 15 to 20 years they would grow into reliable forests to act as buffers against possible natural disasters.

The forest created by Miyawaki method is 30 times dense, 10 times faster to grow, 100 times bio-diverse and 100% natural. After the first two years when periodic watering would not be required, there is no need for any sort of maintenance activity. In fact, the forest thus created is mutually supporting the flora and fauna in a wide spectrum of biodiversity.

Efficacy of the Vetiver:

The Vetiver grass system has been suggested to be one of the popular bio-engineering solutions for eroding unstable banks. This grass has been used in China, Australia, Vietnam, Thailand, Bangladesh, Philippines for canal, dyke and riverbank stabilization (NRC, 1993; Islam et al., 2008). In Vietnam, successful Vetiver trials were made in Quang Ngai province in October 2002 to protect dykes. As initial toe protection method, woven bamboo mats and timber stake groyens were used. Once the bamboo mats have decayed, it was expected that the Vetiver would provide protection to the bank toe. Only after three months of planting, the young beds of Vetiver could trap flood sediments. The successful examples can be seen in the Mekong delta, central Vietnam and Indonesia (Truong et al., 2008). A single hedge of Vetiver grass on the outer slope of a dyke can reduce the wave run-up volume by 55%, and multiple hedges planted along the outer slope contour might result in more reduction, thereby providing a substantial reinforcement of these dykes.

Experience in Bangladesh

The Bangladesh Water Development Board has successfully protected the coastal polderization system from wave erosion where an 87 km.-long earthen embankment was covered with Vetiver and other economic grasses along the slopes in combination with soil-cement mixture bags, zigzag beams and octagonal hollow blocks. These grasses were able to reduce the threat of high tidal surges and cyclonic storms which previously washed-out arable lands and caused infrastructural damage. It has also been used effectively along the Padma River, for slope stabilisation and bank erosion mitigation by high waves and tidal surges (Islam, 2016).

Despite heavy rainfall, Vetiver grass hedges provided the required protection in Barisal and Khulna, preserving the embankment slope from the wave action, with root growth up to 43 cm. and 38 cm. in Barisal and Khulna, respectively. As the root growth in saline zone was comparably lower, an organic supplement should be used at the time of plantation. However, fully grown Vetiver after a period of two months, can also remove some of the salinity present in the soil (Islam et al., 2014).

Concern over introduction of the Vetiver grass in fragile Ecosystem:

All the features discussed above have made this species an excellent option for soil and water conservation, but it is also a problematic invasive species. Once established, it grows very densely and has the potential to displace other plant species including other grasses. Currently, Vetiver is listed as invasive species in China, Fiji, Costa Rica, Anguilla and the

Philippines. This species is highly efficient in absorbing dissolved nutrients such as nitrogen and phosphorus, and its dense root system can directly alter the soil structure and modify or inhibit nutrient and water acquisition by native species. Due to its deep root system, it is difficult to remove manually (Rojas-Sandoval, 2020).

Based on Ding and Wang (1998), Li and Xie (2002) and xiang et al (2002), China studied a total 126 major alien invasive species for their colonity, life form, geographic origin and invasiveness. All 126 major alien invasive species were categorized in three groups (I, II, III), where Vetiver grass was designated as Group II; which invaded area >300 sq. km. exhibiting strong negative influence in the invaded area (Jian Liu et al, 2005). The investigation of vetiver planted for soil and water conservation on a bench terrace in Spain showed that soil depth, water availability and to a lesser extent temperature, adversely influence root development in Mediterranean environments. Combination between native vegetation and Vetiver, shows that the dense, deep and columnar root system cannot develop to the same extent as under its tropical and subtropical environment (Mickovski et al., 2005).

So, the characteristics that make this plant desirable for erosion control are also the characteristics that define an invasive species. Without any specific research on the potential invasiveness of this species, it is not recommended to use this plant for erosion control especially in fragile ecosystem like Sundarban. However, it can be introduced in the non-tidal regime as a pilot project.

Concluding Remarks:

There is a need to recognize that more than a decade is required to establish and grow bio-shields to a size and density that could offer protection against coastal hazards. Till then we must be careful to protect vulnerable stretches. In Sundarban, construction of circuit/ parallel embankment is the best option to save the riparian people from forthcoming disaster. There is hardly any scope of creating bio-shield in the narrow and eroding beach of old Digha or Gangasagar. The construction of an off-shore wave breaker or a series of protruding groyens may be effective to save this tourist hub of West Bengal. The IIT-Madras has been invited to find out the best possible ways of offshore intervention.

Based on the observations of the members of the Expert Committee, learning from the best practices elsewhere and also taking into consideration the opinions of some other Scholars, we can now summarise how does the mangrove ecosystem protect land and people from the storm surges, submergence and erosion. There are several ways in which the system operates.

1. Mangroves reduce the wind speed, by attenuating the energy of the wind while blowing through the dense tree cover. They act as natural buffers between the land and the sea, and apart from sequestering carbon, they also shield against riverbank erosion by stabilizing soil and sediments through organic depositions.
2. Mangroves safeguard low-lying littoral tract by checking excess salt deposition during storm surges and flooding.
3. The uniqueness of Sundarban mangroves primarily lies in its ability to absorb the storm surge through the impenetrably thick cluster of prop-roots, extricating the cyclone of its severest effects. Parts of the islands, where the mangrove cover is less, have been found to be affected badly by the cyclones, whereas the eastern peripheries with a dense cover usually suffer lesser devastation.

While there are several studies on the positive impact of the mangroves in protecting the coastal areas from erosion, and cyclonic storms, the human intervention in mangrove area usually does not follow any scientific pattern where the issue of protection is prioritised. The interventions are made either by the Forest Department or by the Panchayats through MGNREGA. While work of Forest department is focused on improving the green cover, MGNREGA is keen on creating employment opportunities. The Irrigation Department is entrusted with the task of embankment building and repairing the post-cyclone damages. Naturally, the holistic science of coastal protection is not prioritised till date by either of the programmes. This is for the first time we strongly recommend to harmonise all inter-departmental efforts and the task of coordination is already in progress. Thus, our forthcoming approach will combine civil engineering and bio-engineering to pave a new path for saving the human society as well as the fragile ecosystem of the coastal West Bengal.

Annexure IA: List of Extremely Vulnerable Right Banks

Sl. No.	Name of Block	Number of Concave Banks	Total Length of Concave Banks (m)	Length of Longest Curve (m)	Length of Shortest Curve (m)	Total Length of Existing Mangrove on Concave Banks (m)	Total Length of Pucca Embankments on Concave Banks (m)
1	Sagar	3	12214	5022	3585	0	2560
2	Namkhana	5	17189	6633	1414	5500	700
3	Pathar Pratima	30	59799	4898	368	4300	8912
4	Kultali	21	31248	3649	300	18750	2235
5	Basanti	16	29001	8605	360	8900	5400
6	Gosaba	28	52336	5008	610	5600	4520
7	Hingalganj	31	39221	4543	253	0	6589
8	Kakdwip	3	6908	3474	1398	0	0
9	Mathurapur-I	10	2448	420	131	0	0
10	Mathurapur-II	6	8917	3091	700	0	0
11	Jaynagar-l	4	3287	1020	653	0	0
12	Jaynagar-lI	3	1761	773	449	0	0
13	Canning-l	3	1161	420	325	0	0
14	Sandeshkali-l	12	19285	2964	811	0	2050
15	Sandeshkhali-II	8	12356	5287	607	200	260
16	Minakhan	9	7406	1207	424	0	0
17	Hasnabad	8	14544	3328	628	0	800
18	Haroa	7	4803	1099	473	0	750
		207	**323884**			**43250**	**34776**

Annexure IA: List of Extremely Vulnerable Left Banks

Sl. No.	Name of Block	Number of Concave Banks	Total Length of Concave Banks (m)	Length of Longest Curve (m)	Length of Shortest Curve (m)	Total Length of Existing Mangrove on Concave Banks (m)	Total Length of Pucca Embankments on Concave Banks (m)
1	Sagar	0	0	0	0	0	0
2	Namkhana	5	17557	5579	1926	1800	2699
3	Pathar Pratima	24	42973	5914	315	620	4903
4	Kultali	13	20530	3208	932	7650	0
5	Basanti	6	10930	2811	780	0	1700
6	Gosaba	22	38765	3585	653	2500	2524
7	Hingalganj	18	28339	4034	461	0	8925
8	Kakdwip	4	8556	4300	650	0	1000
9	Mathurapur-I	13	3243	553	132	0	0
10	Mathurapur-II	9	13220	2600	742	0	0
11	Jaynagar-l	0	0	0	0	0	0
12	Jaynagar-II	5	2807	745	411	0	0
13	Canning-l	6	3103	838	297	0	0
14	Sandeshkali-l	7	9992	1948	887	0	960
15	Sandeshkhali-II	19	16473	1751	295	0	2770
16	Minakhan	9	8316	1998	391	0	0
17	Hasnabad	5	5425	1354	779	0	0
18	Haroa	6	5189	1153	584	0	1000
		171	**235.4 km.**			**12.6 km.**	**26.5 km.**

Annexure II: Sustainable Agriculture

The agrarian economy of Sundarban has been facing a serious challenge due to ingress of saline water. The natural process of flushing out of salinity from the top soil may take two or three rainy seasons. Ingress of saline water from Bay of Bengal often makes farmland saline. Rainfall varies from 1500-1800 mm. per year mostly precipitated during monsoon months. Soils are silty-clay type, rich in Mg^{2+}, Na+, Ca^{2+}, Cl^{-}, SO^{2-} salts. Fertility varies from low to medium, pH varies from 7.5-8.5. Average amount of soluble salt in soil varies from 3-18 m-mhos/cm. Due to presence of high Mg, the soils become hard and dry and get deflocculated. Because of these facts the agriculture of the region is predominantly rain-fed and cropping pattern is almost mono-cropped (Bandyopadhyay et al., 2016). Only 4% of the cultivated area of the coastal zone can be irrigated with available sweet water and the lands generally remain fallow during rest six to seven months *i.e.* in winter and summer season (Mainuddin et al., 2020; Ray et al., 2020).

Soil salinity is the most dominant limiting factor in the region, especially during the dry season. It affects certain crops at different levels of soil salinity and at critical stages of growth, which reduces yield. Even total crop failure occurs in extreme conditions (Bell et al., 2018). Fertility status of most saline soils range from low to very low in respect to organic matter content, nitrogen, phosphorus and micronutrients like zinc and copper (Banerjee et al., 2018, 2019) Fertilizer use efficiency cannot be determined properly. The texture of most of the saline soils varies from silty clay to clay. Land preparation becomes very difficult as the soil dries out. Deep and wide cracks develop, and surface soil becomes very hard. Perennial water-logging due to inadequate drainage restricts farming in lowlands. Heavy monsoon rainfall causes delay in transplanting of rainy season crops and sometimes water logging damages the standing crop. The following table describes the rice varieties which are suitable in Sundarban.

Table 1: Suitable rice varieties for coastal region of West Bengal

Type of cultivars	Name of the cultivars	Duration (seed to seed) in days	General characteristic features
High Yielding Variety	Pratikkha	125	Salinity tolerant; can withstand water stagnation; resistant to sheath blight disease; soft straw
	Santoshi	135	Salinity tolerant; absolutely disease-free
	Sabita	140	Salinity tolerant; can withstand water stagnation; higher incidence of stem borer; incomplete seed setting
	Super Shyamali	140	Salinity tolerant; long grain; good for 'moori' (puffed rice) making; moderate incidence of stem borer
	Swarna masuri	130	Salinity tolerant; susceptible to sheath blight disease
	Gosaba 5	135-140	Salinity tolerant; can withstand water stagnation; Coarse Grain type
Indigenous	Black rice	140	Salinity tolerant; grain colour black; absolutely disease-free
	Dudheswar	125	Salinity tolerant; scented rice; can withstand water stagnation; fine grain; good for 'moori' making; fine straw; moderate incidence of stem borer
	Kerala sundari	125	Salinity tolerant; can withstand water stagnation; fine grain
Aromatic	Radhatilak	130	Salinity tolerant; scented rice; can withstand water stagnation
	Gobindabhog	130	Salinity tolerant; scented rice; fine straw and palatable for livestock; moderate incidence of stem borer

Growing crops in the Rabi season:

Different Rabi/summer crops including off-season high value vegetables like broccoli, capsicum, onion, garlic, okra, water melon, french bean, Indian spinach, tomato, pumpkin, bitter gourd, snake gourd, cucumber, chilli, mung bean, mustard, cabbage, cauliflower, knol-khol, beetroot may be grown with mulching or without mulching (provided lifesaving irrigation is available from nearby pond).

Table 2: Promising varieties of rabi/summer crops identified for the coastal region of Gangetic deltas

Crop	Identified varieties	Season	Land situation
Mustard	B-9, Pusa Bold, Varuna, Kranti, TM 143 and TM 204	Winter (late sown)	Medium
Sesame	Savitri, Rama, Tilottoma	Summer	Medium
Lathyrus	Nirmal, Ratan, Bidhan Khesari -1	Winter (pyra cropping)	Medium and medium-low
Lentil	Moitrayee	Winter (pyra cropping)	Medium and medium-low
Sunflower	KBSH 44, KBSH 53, PAC361, Sunbred 275, Aditya	Winter (late sown)/ spring	Medium
Mungbean	PM 05, IPM 99-125, IPM 2-3 Samrat, Bireswar, Sukumar	Summer (early sown)	Medium and medium-low
Blackgram	Sarada, Pant U31	Summer (early sown)	Medium and medium-low
Maize	P 3396, 3392, Rajkumar, Yuvraj Gold, PAC 740	Winter (late sown) Spring (15-30 Jan.)	Medium Medium
Potato	Kufri Pukhraj, Kufri Jyoti, S-6, S-52	Winter (late sown) under Zero Tillage+ straw mulch	Medium

It has been observed that Furrow irrigation can reduce irrigation water use by 30% to 50% compared to flood irrigation method. Growing potato under zero tillage (ZT) and straw mulch after kharif rice has been proved to be an outstanding technology of the coastal farmer and farm families. It has been found that the technology is undoubtedly effective in reducing late season salt accumulation and weed infestation vis-à-vis increasing nutrient and water use efficiency. It would really be a remunerative as well as sustainable eco-friendly technology for the homestead farming and the coastal farmers having meagre acreage of land. Net benefit has further been enhanced by applying foliar fertilizers. Inclusion of pulses, as utera crop/ pyra, is a potential option in rice-fallow areas with a dual advantage of crop diversification for sustainable production and area expansion of pulses for human nutrition. Foliar application of 2% di-ammonium phosphate (DAP) provides better yield and growth of utera lentil and lathyrus. Use of mini pond in 3-6% of the total service area for storing water in the wet season and use of them in Rabi season for growing crops as a part of integrated farming system (IFS) was found suitable and highly profitable. Low-cost drip irrigation system is very promising and financially feasible with favourable economic return and payback period. Drip irrigation at different frequency with tomato shows that drip irrigation at 80 % ETo with straw mulching provided significantly higher yield. Homestead/domestic small-scale drip irrigation using plastic bottle beside plants such as okra, tomato, onion, knolkhol, beet, chilli etc. are also profitable. Adoption of suitable and profitable cropping patterns i.e. Kharif rice-ZT potato (with straw mulch)-green gram, Kharif rice-ZT potato (with straw mulch)-fallow, Kharif rice-maize-fallow, etc. may be adopted for maximization of total productivity.

Rearing animals (goat, sheep, cow etc.) and birds (foul) on the upland domestic area, planting fruit and orchard crops (papaya, sapota, guava, drumstick etc.) at the boundary of the house, growing varied seasonal vegetables including leafy vegetables on the wide bund (bund cultivation), fitting different agronomic as well as horticultural crops as per land topography and rearing fish and duck in the water bodies under land shaping system is the most promising integrated farming system (IFS) of the coastal ecology. It not only reduces the risk and strengthens the insurance of coastal farming but also escalates the overall annual farm family income, maintains sustainability as well as enables the agrarian sector to contribute towards saving the coastal ecology without hampering their livelihoods.

Table 3: Impact of different land shaping models on cropping pattern under coastal saline environment

Before invention (Existing cropping pattern)		After invention (changed cropping pattern)		
Rainy season	Post rainy dry season/summer season	Land situation created	Rainy season	Post rainy dry season/summer season
Rice	Mostly fallow	***Farm pond model***		
		Pond	Fish	Fish
		Dykes	Vegetables and fruit crops/ multipurpose tree species (MPTs)	Vegetables and fruit crops/ multipurpose tree species (MPTs)
		High land	Vegetables	Vegetables
		Medium land	HYV rice	Vegetables, low water requiring field crops
		Low land	Rice+Fish	Low water requiring crops/ vegetables, short duration rice
Rice	Mostly fallow	***Deep farrow and high ridge model***		
		Furrows	Fish	Fish
		Ridges	Vegetables and fruit crops/ multipurpose tree species (MPTs)	Vegetables and fruit crops/ multipurpose tree species (MPTs)
		Low land	Rice	Low water requiring land field crops/vegetables
Rice	Mostly fallow	***Paddy cum fish model***		
		Trenches	Fish	Fish
		Dykes	Vegetables and fruit crops/ multipurpose tree species (MPTs)	Vegetables and fruit crops/ multipurpose tree species (MPTs)
		Low land	Rice	Low water requiring land field crops/vegetables
Rice	Mostly fallow	***Broad bed and furrow model***		
		Bed	Vegetables and/fruit crops	Vegetables, pulses and/fruit crops
		Furrow	Fish/Rice+Fish	Fish

† Land situations were dominated by low-lying with deep waterlogging in rainy season (>30 cm of standing water).

†† Low water requiring crops indicated cotton, sunflower, mustard etc.

Annexure III: Coastal Regulation Zone (CRZ)

(as per MOEFCC, GOI, Notification 2011 & 2019)

What is Coastal Regulation Zone (CRZ)?

Coastal Regulation Zone is the land area from High Tide Line (HTL) to 500 m. on the landward side along the sea front. In case of tidal influenced rivers/creeks CRZ is the land area between HTL to 100 m. or width of the creek whichever is less on the landward side along the tidal influenced water bodies that are connected to the sea.

CRZ restricts what?

The CRZ notification restricts the setting up and expansion of any industry, **operations or processes** and manufacture or handling or storage or disposal of hazardous substances as specified in the Hazardous Substances (Handling, Management and Transboundary Movement) Rules, 2009 in the CRZ.

Why is CRZ necessary?

- To conserve **and protect the environment** and maintain coastal integrity.
- To address climate change issues, mitigate **natural hazard** and disaster.
- Ensure livelihood security of the **local community** through sustainable development.

Different type of Coastal Regulation Zone:

CRZ – I (A & B) *[Ecologically sensitive Areas (ESA) & Intertidal region]*

CRZ – II *[Already developed Area, with services and amenities]*

CRZ – III *[Undeveloped Area (semi urban/rural coast), which do not belong to CRZ-I or CRZ-II]*

*Here in **CRZ III, NO DEVELOPMENT ZONE (NDZ)** area is up to 200mts from HTL on the landward side in case of seafront and 100mts along tidal influenced water bodies or width of the creek whichever is less.*

CRZ – IV (A & B) *[Sea & Tide Influenced water body]*

Provisions for erosion control measures under the CRZ Notifications 2011 and 2019.

ABSTRACT:

Erosion control measures, foreshore facilities and public utilities with in CRZ are permissible but regulated activities under the CRZ Notifications 2011 and 2019. Which means, an application in (Form I as per the procedure established in para 4.2 of 2011 MOEFCC notification) has to be submitted by the project proponent to the West Bengal Coastal Zone Management Authority (WBCZMA), Environment Department, Government of West Bengal.

1. *For processing these applications and CRZ clearance WBCZMA is presently following the 2011 notification and the MOEFCC approved COASTAL ZONE MANAGEMENT PLAN (CZMP) prepared as per the 2011 notification.*
2. *As per the 2011 notification, all projects under any CR Zones I,II,III,IV as mentioned above, if recommended by the WBCZMA, will be finally considered for approval by the National Coastal Zone Management Authority (NCZMA), MOEFCC, Government of India.*
3. *The MOEFCC stipulated CZMP as per 2019 notification is under the process of preparation. As per the 2019 notification, WBCZMA can give final approval for projects falling under CRZ II & CRZ III, without forwarding to MOEFCC.*

Specific Rules provisions:

1. ***Para 3 (i) of 2011 MOEFCC notification permits*** **erosion control measures** within CRZ and define the **erosion control measures** as one of the 'foreshore facilities'.

2. ***Para 4 (f) of 2011 MOEFCC notification says about Regulation of permissible activities in CRZ area:***

   4(f)" construction and operation for ports and harbours, jetties, wharves, quays, slipways, ship construction yards, breakwaters, groynes, **erosion control measures** [and salt works]*36**"**

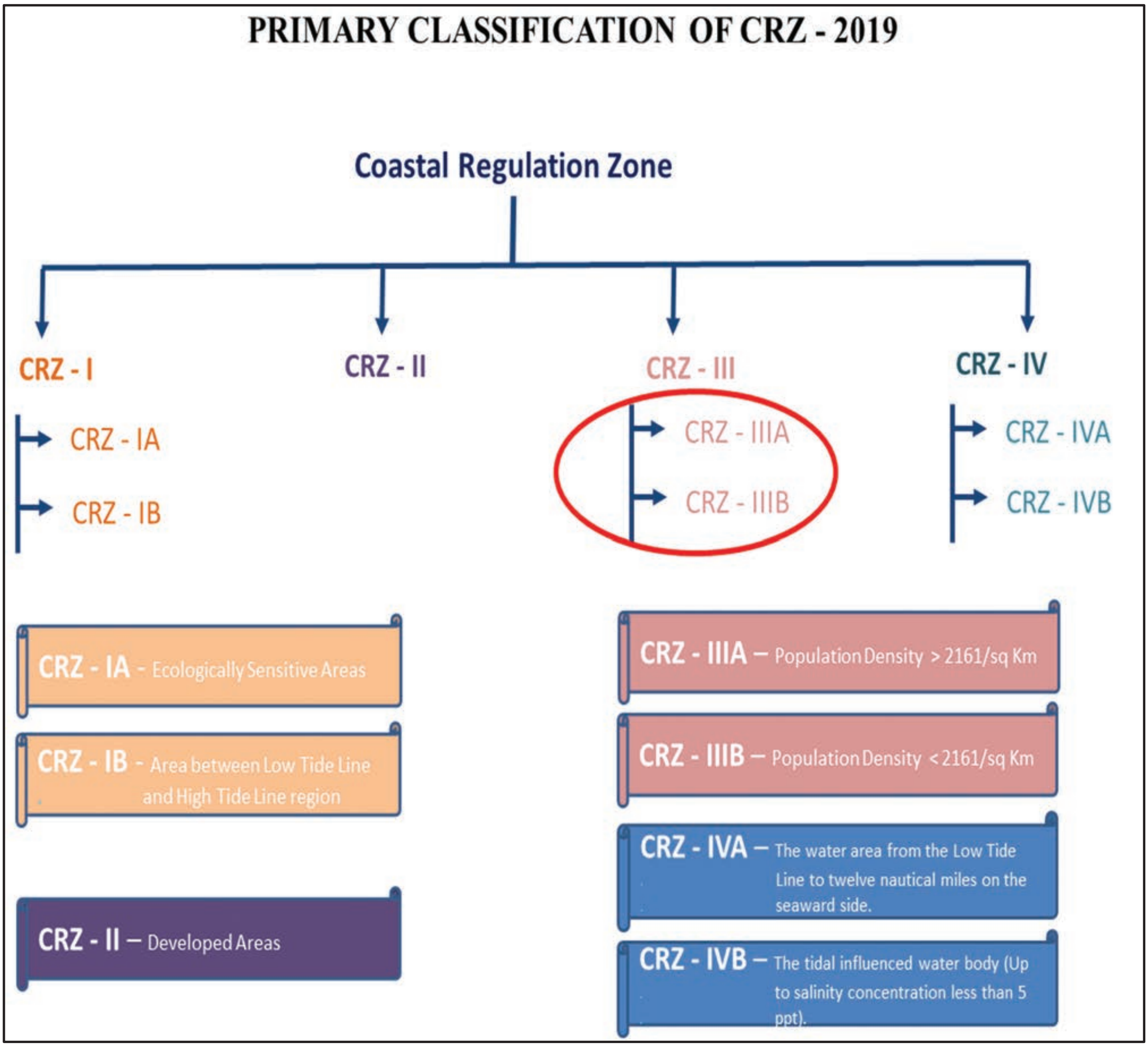
   This regulation means that an application as perthe procedure established in para 4.2 of the 2011 notification is required.

3. As per 2019 notification para 5 mentions about the **regulation of permissible activities in CRZ**. Here public utilities and erosion control measure is permissible even in CRZ 1 (most strictly protected), however the project proponent has to apply to WBCZMA for CRZ clearance. A detail of provision is quoted below.
4. Para 7 of 2019 notification says

   "CRZ clearance for permissible and regulated activities- Delegation:

   (i) All permitted or regulated project activities attracting the provisions of this notification shall be required to obtain CRZ clearance prior to their commencement"

Additional information below regarding CRZ classification:



CZMP 2011 & CZMP 2019

(Basic comparison)

Coastal Regulation Zone		
CRZ	Extension	
	2011	2019
Sea Front (Landward Side)	500 mts	500 mts
Tide Influenced Waterbody (Creek)/No Development Zone (NDZ)	100 mts/ width of the creek whichever is less	**50mts / width of the creek whichever is less**
No Development Zone (NDZ) at Sea Front	200 mts	No Development Zone (NDZ) **CRZ- IIIA at Sea Front – 50mt.** No Development Zone (NDZ) **CRZ- IIIB at Sea Front – 200mt.**
Sea Bed area (Seaward Side)	12 nautical miles	12 nautical miles

Description

CRZ- IIIA	Such densely populated CRZ-III areas, where the population density is more than 2161 per square kilometre as per 2011 census base, shall be designated as CRZ–III A and in CRZ-III A, area up to 50 meters from the HTL on the landward side shall be earmarked as the 'No Development Zone (NDZ)', provided the CZMP as per this notification, framed with due consultative process, have been approved, failing which, a NDZ of 200 meters shall continue to apply.
CRZ-IIIB	All other CRZ-III areas with population density of less than 2161 per square kilometre, as per 2011 census base, shall be designated as CRZ-III B and in CRZ-III B, the area up to 200 meters from the HTL on the landward side shall be earmarked as the 'No Development Zone (NDZ)'.

Annexure IV:

Government of West Bengal
Environment Department
Prani Sampad Bhavan, 5 th Floor, LB 2, Sector Ill
Salt Lake, Kolkata 700106

No: 016/ACSENV/2021 June 02, 2021

NOTIFICATION

Whereas there is an urgent need to undertake measures to protect the coastal belt of West Bengal from steady erosion as also from the devastation caused by cyclonic thunder storms, the frequency and severity of which has been seen to be growing due to factors of climate change;

2. Whereas the environmental role played by natural vegetation in mitigating soil erosion, adverse impact of climate change as well as cyclones in the coastal areas has been extensively documented and universally acknowledged;

3. Whereas West Bengal has a large number of rivers, irrigation canals and drainage channels and their river banks/slopes/earthen embankments are subject to erosion, which leads to loss of huge quantities of fertile soil annually besides causing loss of homesteads;

4. Whereas earthen embankments/river banks/slopes can be strengthened further through adoption of environment-friendly vegetative practices thus bringing down repair and maintenance costs;

5. Now, therefore, an Expert Committee on Protection of Coastal Areas and Earthen Embankments Through Vegetative Solutions is hereby set up with the following composition:

i. Dr. Kalyan Rudra, River Expert and Chairman, West Bengal Pollution Control Board — Chairperson

ii. Additional Chief Secretary, Environment Deptt, GoWB Co-chairperson

iii. Chairman, West Bengal Biodiversity Board Member

iv. Dr. Krishnendu Acharya, Former HOD, Botany, Calcutta University — Member
v. Prof. Sunando Bandyopadhyay, Geography Deptt., Calcutta University — Member
vi. Dr. S. C. Santra, Environmental Science Deptt., Kalyani University Member
vii. Dr. Koushik Brahmachari, Department of Agronomy, BCKV, Nadia — Member
viii. Mr. Vincent Paulraj, Social Activist and Core Committee Member, Indian Vetiver Network, Coimbatore, T.N. — Member
ix. Dr. Sugata Hazra, School of Oceanographic Studies, Jadavpur University _ Member
x. Dr. K. Karthigeyan, Scientist E, Botanical Survey of India — Member
xi. Dr. Neera Sen Sarkar, Department of Botany, Kalyani University — Member
xii. Dr. Priyank Pravin Patel, Assistant Professor, Geography Deptt., Presidency University, Kolkata — Member
xiii. Shri Saikat Saha, Subject Matter Specialist, Krishi Vigyan Kendra, BCKV, Nadia _Member
xiv. Ms. Neelam Meena, IAS, Director, Institute of Environmental Studies and Wetland Management — Member Secretary
xv. Shri K. Balamurugan, IFS, Chief Environment Officer and Chief Technical Officer, East Kolkata Management Authority — Member
xvi. An official of the Irrigation and Waterways Deptt., GoWB not below the rank/scale of Superintending Engineer — Member
xvii. An official of the Deptt. of Forests, GoWB not below the rank/scale of Joint Secretary — Member
xviii. An official of the Sundarban Affairs Deptt, GoWB not below the rank/scale of Joint Secretary — Member
xix. Shri Dipankar Bhadra, former Director of Agriculture, GoWB Member
xx. Shri Sudipta Porel, WBCS (Exe), ADM & DLLRO, Purba Medinipur – Member
xxi. Dr. Sukamal Sarkar, Assistant Director of Agriculture, GoWB — Member
xxii. Ms. Kasturi Ghosh, Assistant Director of Agriculture, GoWB Member
xxiii. Shri Suprabhat Chatterjee, District Nodal Officer, MGNREGA, Purulia — Member
xxiv. Dr. Anirban Roy, Research Officer, West Bengal Biodiversity Board — Member

6. Terms of Reference:

a) To examine the various options of vegetative practices and plantations (i) for the protection of the coastal belt of West Bengal, including the environmentally fragile Sundarbans region, and (ii) protection of earthen embankments of rivers/

rivulets/ irrigation channels, through plantation of trees/shrubs/grass turf, etc. and other environmentally-friendly measures.

b) To study the international and national best practices in this respect and assess the feasibility of adopting the same, in whole or in part, for West Bengal keeping in mind its unique agro-climatic characteristics.

c) To recommend, based on a study of their comparative utility, longevity, costing and any side effects (on agriculture, pisciculture, water table management, weed management, etc.) the various types of plant species and grass turfs found to be feasible for adoption in different regions of the State, their planting patterns, planting schedules, maintenance schedules, etc.

d) Any other issue pertinent or incidental to the subject

e) The Committee will present its Report to the Environment Department not later than 3 Pt July 2021.

7. The Expert Committee may invite any expert or organization or person for consultation and all State Government Departments and their para-statal organisations/ agencies shall render necessary assistance, as and when called for.

8. The secretarial assistance to the Committee shall be provided by the Institute of Environmental Studies and Wetland Management and all incidental expenses, including any sitting fees of expert members, etc. will be borne by it.

(Vivek Kumar)
Additional Chief Secretary a

References:

- Bandyopadhyay S.(2019): Sundarban: A Review of Evolution and Geomorphology. World Bank Technical Report # 138927, Washington DC (doi:10.13140/RG.2.2.25774.54084).
- Bandyopadhyay Sunando, Dasgupta Susmita, Khan Zahirul Huque and Wheeler David (2021): Spatiotemporal Analysis of Tropical Cyclone Landfalls in Northern Bay of Bengal, India and Bangladesh. Asia-Pacific Journal of Atmospheric Sciences; Korean Meteorological Society, Springer(https://doi.org/10.1007/s13143-021-00227-4).
- Black, K.P., Reddy, K.S., Kulkarni, K.B., Naik, G.B., Shreekantha, P. and Mathew, J., 2020. Salient Evolution and Coastal Protection Effectiveness of Two Large Artificial Reefs. Journal of Coastal Research, 36(4), pp.709-719.
- Braatz Susan, Fortuna Serena, Broadhead Jeremy, and Leslie Robin (Edited, 2006): Coastal protection in the aftermath of the Indian Ocean tsunami: What role for forests and trees? Proceedings of the Regional Technical Workshop, Thailand.
- Brown, S. And. Nicholls, R.J (2015): Subsidence and human influences in mega deltas: The case of the Ganges–Brahmaputra–Meghna. Science of the Total Environment 527–528 (2015) 362–374
- Budinetro HS (2019) Low cost treatment of river bank erosion. In: Proceedings of APHW 2004 2nd international conference on hydrology and water resources in Asia Pacific Region, Kyoto, Japan
- Centre for Science and Environment(2012): Living with Changing Climate / Impact, Vulnerability and Adaptation Challenges in Indian Sundarbans.
- Chowdhury, M.S.N., Walles, B., Sharifuzzaman, S. *et al.* Oyster breakwater reefs promote adjacent mudflat stability and salt marsh growth in a monsoon dominated subtropical coast. *Sci Rep* **9,** 8549 (2019). https://doi.org/10.1038/s41598-019-44925-6
- Chaudhury, S. (2021):The Problem of Erosion in the Coastal Stretch from Subarnarekha to Pichhabani in Purba Medinipur District of West Bengal (unpublished).
- Dalton PA, Smith RJ, Truong PNV (1996) Vetiver grass hedges for erosion control on a cropped flood plain: hedge hydraulics. Agric Water Manag 31:91–104
- Ding, J.Q. & Wang, R. (1998) Invasive alien species and their impact on biodiversity in China. *China's biodiversity: a country study* (ed. by The Compilation Group of China's Biodiversity), pp. 58– 63. China Environmental Science Press, Beijing.
- Eubanks CE, Meadows D (2002) A soil bioengineering guide for streambank and lakeshore stabilization. United States Department of Agriculture Forest Service, San Dimas Technology and Department Center, New York
- Harris, L.E., 2006. Artificial reefs for ecosystem restoration and coastal erosion protection with aquaculture and recreational amenities. Reef Journal, 1(1), pp.235-246.
- Hazra, Sugata (2021): Building with Nature: a green option in the Indian Sundarbans Delta. Unpublished Note submitted to this Committee.
- IPCC, 2013: Summary for Policymakers (AR5). 2013:1139.
- IPCC, 2019: Summary for Policymakers. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.- O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, M. Nicolai, A. Okem, J. Petzold, B. Rama, N. Weyer (eds.)].
- Islam MS (2016) Bio-engineering techniques using Vetiver system for slope stabilization: river bank erosion perspective. Paper presented at the workshop on mitigation of river bank erosion through bio-engineering techniques on Brahmaputra river in Assam, Guwahati.

- Islam MS, Badhon FF (2016) Characterization of soil-root system to determine stability of vegetated slopes. In: Proceedings of the 3rd international conference on the advances of civil engineering, Chittagong, Bangladesh
- Islam MS, Bhuiyan MKH, Hossain MZ (2008) Vetiver Grass as a Potential Resource for Rural Development in Bangladesh. Agricultural Engineering International: CIGR Journal, 5(X):1-18
- Islam MS, et al. (2020) Investigation of Climate Resilient Slope Protection of Embankments. Coastal Climate Resilient Infrastructure Project (CCRIP) Package No: CCRIP-S-05(B).Local Government Engineering Department (LGED), Government of the People's Republic of Bangladesh. Bangladesh University of Engineering and Technology (BUET), Dhaka.
- Islam MS, Shariar BAM, Parshi FN (2014) Bio-technical solution for dyke protection in saline zone of Bangladesh. Paper presented at The 2014 World Congress on Advances in Civil, Environmental and Materials Research (ACEM14), Busan, August 24-28.
- Kafle G, Balla MK (2008) Efectiveness of root system of grasses used in soil conservation in PaundiKhola sub watershed of Lamjung District, Nepal. The Initiation, Student Forum for Forestry Research and Environment (SUFFREC), pp 121–129
- Li MH, Eddleman KE (2002) Biotechnical engineering as an alternative to traditional engineering meth- ods A biotechnical streambank stabilisation design approach. Landsc Urban Plan 60:225–242
- Li, Z.Y. & Xie, Y. (2002) *Invasive alien species in China*. China Forestry Publishing House, Beijing.
- Liu, J., Liang, S.C.L, Liu, F.H., Wang, R.Q., Dong, M. (2005): Invesive alien plant species in China: regional distribution patterns. Diversity and Distributiona,11, 341-347.
- Maffra C, De Moraes MT, Sousa R, Sutili FJ, Pinheiro RJB, Soares JMD (2017) Evaluation methods of plants inluence and contribution on slope stability. Sci Agrar Parana 18(4):129–143
- Mickovski, S.B, Beek, L.P.H. van and Salin, F.(2005): Uprooting of vetiver uprooting resistence of vetiver grass (Vetiveriazizanoides).https://researchonline.gcu.ac.uk/en/publications/uprooting-of-vetiver-uprooting-resistance-of-vetiver-grass-vetive
- Mitsch William J.(2012): What is Ecological Engineering. Ecological Engineering, vol.45,5-12.
- Mukherjee, Subrat and Sen Sarkar, Neera (2021): Re-Planning Embankments/ Vegetative Solutions for Embankment Stability in Indian Sundarbans. Banabithi, July 2021.
- Mulyono A, Subardja A, Ekasari I, Lailati M, Sudirja R, Nirgrum W (2018) The hydrodynamics of vegetation for slope stabilization. IOP Conf Ser Earth Environ Sci 118:012038. https://doi.org/10.1088/1755-1315/118/1/012038
- National Research Council 1993 Vetiver Grass: A Thin Green Line Against Erosion. National Academy Press, Washington, DC.
- Rojas-Sandoval, J.(2020):*Chrysopogonzizanioides.Invasive species Compendium. Willingford, UK: DoI: 10.1079/ISC. 18528 .20203483484).w.w.cabi.org.)*
- Rudra, Kalyan (2018): Rivers of the Ganga-Brahmaputra-Meghna Delta/ A Fluvial Account of Bengal. Springer.
- Rudra, Kalyan (2021): Changing River Courses in Bengal (1780-2020); In Riverine System: Understanding the Hydrological, Hydrosocial and Hydro-heritage Dynamics; Edited by Abhijit Mukherjee. Capital Publishing Company, New Delhi.
- Sarkar Dibyendu (2021): Natural Protection from natural calamities: the Case of Coastal areas of West Bengal. http://blog.ecovocal.com/index.php/2021/07/01/natural-protection-from-natural-calamities-in-the-indian-sundarbans/
- Xiang, Y.C., Peng, S.L., Zhou, H.C. & Cai, X.A. (2002): The impacts of non-native species on biodiversity and its