Journal of Coastal Conservation 9: 171-178, 2003

Application of a 'bio-engineering' technique to protect Ghoramara Island (Bay of Bengal) from severe erosion

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Abstract. Ghoramara Island is located ca. 150 km south of Kolkata, Bay of Bengal, India, in the Sundarban Delta complex. This sparsely populated island is suffering from severe coastal erosion and areal reduction for the last three decades, which results in the loss of major areas on the northwest coast. Both numerous households and a significant area of agricultural land and coastal stretches for fish drying have been lost. This has rendered thousands of people homeless as 'environmental refugees'. In the present paper an attempt is made to study the erosion and accretion process through time series analysis using a GIS technique. Also, a study of remedial measures to protect the island using a 'bio-engineering' technique is reported in this paper. It has been shown that, in the absence of protection measures, the eastern shore will merge with the Indian mainland during the next 25 years, while the western part will be completely washed off.

Keywords: Bay of Bengal; Coastal accretion; Coastal erosion; Geotextile, GIS; Mangrove; Remote sensing; Shore protection; Time series analysis.

Abbreviation: SOI = Survey of India.

Introduction

The well-known Sundarban Delta forms part of both India and Bangladesh. It is a confluence of several river systems from both countries. The major part of this system is found in Bangladesh, but the smaller Indian part is also very important as a major environmental force in the eastern part of India. In most of the cases it is evident that this part of Sundarban protects the eastern part of India. In recent times, this sensitive deltaic system is gradually getting degraded, may be due to anthropogenic activity or global environmental changes. This includes degradation of the mangrove and erosion-accretion, problems regarding the mixture of fresh and salt water due to sedimentation in the creek and frequent tidal floods. This degradation may have started as early as 1777, when reclamation started by constructing earthen embankments. The island surface level was below the high tide line. The construction of the embankment restricted the saline water flood on the island. Some of the islands, e.g. Lohachara and Suparibhanga disappeared entirely, while Kabasgadi shifted from its original position and attached to the main land of India; on the other hand Balaribar Island is gradually emerging; it plays an important role in the estuarine hydrodynamics of the area. This may determine the severity of erosion and form a scenario of accretion on the estuarine islands. The present paper reports on a pilot study of estuarine erosion and accretion in relation to island restoration, initiated on the small island of Ghoramara.

This island is located at 88°07'30" E and 2°55'00" N with an areal extent of 8.18 km^2; see the Survey of India (SOI) topographic sheet No. 79C/1, 1968, Scale 1 : 50 000). The major villages on this Island include Khasimara, Baishnabpara, Baghpara, Raipara, Mandirtala, Chunpuri and Khasimara Char (Fig. 1). The population of this island was ca. 5000 (Census Report 1991), but this number is decreasing rapidly. The major professions of the inhabitants of this island are agriculture, fishing (mainly fish culture) and prawn seed collecting. The island is under severe threat of erosion in the northwest, while it is marginally growing through accretion in the southeast. The rate of erosion is much higher than the accretion. As a result this island has lost 75% of its land area during the past 30 years. The inhabitants have already lost the major villages Khasimara, Baishnabpara and Khsimara Char (Fig. 1). People who lost their home were compelled to leave the island and moved to Kakdwip, Sagar Island or elsewhere. They may be recognized as 'environmental refugee', because the environmental degradation due to natural/anthropogenic activities is responsible for the permanent loss of habitat.

So, coastal erosion and accretion has a remarkable sociological impact on the inhabitants of this island. In this study an attempt has been made to estimate the

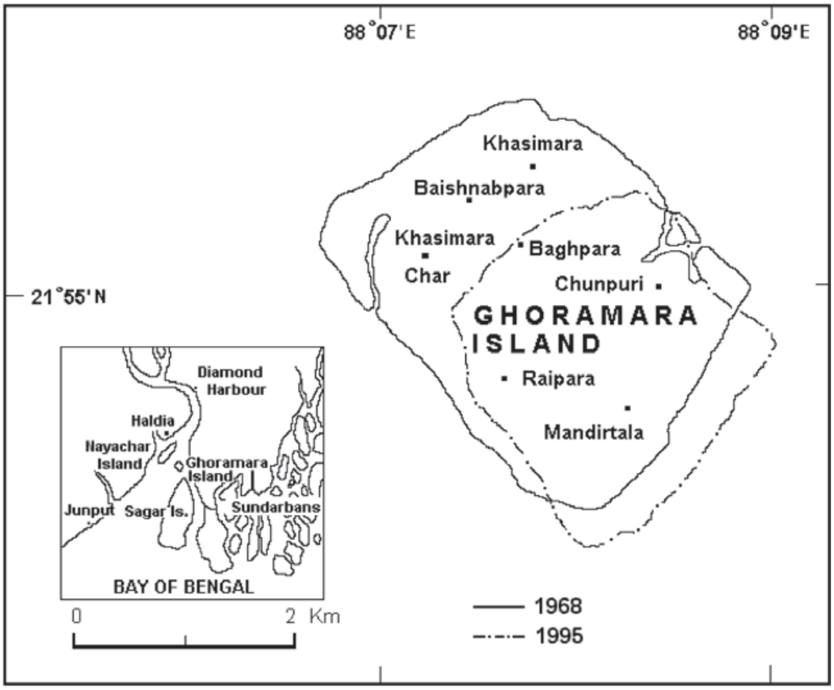

Fig. 1. Location of Ghoramara Island in the Bay of Bengal and devastated areas on the island (after Ghosh et al. 1997).

rate of degradation and remedial measures for the protection of the island, using a bio-engineering technique which is described in this paper. This environment-friendly technique may be appropriate for protection of this sensitive island.

Time series analysis

A time series analysis over 30 years has been performed using satellite imagery obtained from the Indian Remote Sensing Satellite from different years and the SOI topographic sheet. The SOI topo-sheet No. 79C/1, surveyed during 1967-1968 (assuming the data of 1968) was considered as base data and the satellite imagery of IRS-1B: LISS II (Path-Row: 18-52) of 05 January 1995 and 18 January 1999 were superimposed using GIS technique to obtain the time series changes in configuration and shoreline shifting of the islands.

The location map and the detailed map of the island were drawn on a tracing sheet from the SOI topo-sheet. The detailed configuration of Ghoramara Island during 1967-1968 (SOI topo-sheet) was zoomed up using pro-comp machinery for the adjustment of scale of the map and drawn in the tracing sheet. The time series superimposition of different years from different data sources was performed by means of a grid (latitude, longitude) matching technique. The high tide line marked on the SOI topo-sheet was considered as the shoreline – the satellite imagery is obtained at a fixed time and it does not indicate the highest diurnal tidal condition for that date. The correction was made by considering the tidal condition at the time of image acquisition obtained from tide tables available at the Kolkata Port Trust, and the slope of the island at the shoreline. The Kolkata Port Trust regularly carries out continuous tidal measurements and publishes the results.

The area of the island was measured in different years using a planimeter; this was verified through the traditional method using a transparent graph sheet. The computation error was corrected algebraically; the corrected area is presented in Table 1. The net loss of land was then calculated for 1995 and 1999 using the data of 1968 as a base. The actual loss of land on the northwestern part and gain of land in the southeastern part over 31 years (1968-1999) were also calculated from the map (Fig. 2) and are presented in Table 2.

Observations on Ghorama Island

The geomorphological changes of Ghoramara Island, observed from the SOI topo-sheet, satellite imagery (FCC) and field visit for different years, are as follows:

Table 1a. Changes in net area of Ghoramara Island during 1968-1999.

Item	SOI topo-sheet No. 79C/1 (Surveyed 1967-1968)	IRS-1B:LISS II: Satellite imagery (P-R: 18-52) 05 January 1995	18 January 1999
Area (km^2)	8.1775	3.1900	3.0455
Areal changes (km^2)	Base Data	– 4.9875	– 5.1320
Rate of change (km^2.yr^{-1})	Base Data	– 0.1847	– 0.1655

Table 1b. Changes in net area of Nayachar Island during 1968-1999.

Item	SOI topo-sheet No. 79C/1 &79B/4 (surveyed 1967-1968)	IRS-1B:LISS II: Satellite imagery (P-R: 18-52) 05 January 1995	18 January 1999
Area (km^2)	17.9990	74.9980	74.1464
Areal changes (km^2)	Base data	56.9990	56.1474
Rate of change (km^2/yr^{-1})	Base data	2.1111	1.8112

Table 2a. Erosion/accretion at Ghoramara Island during 1968-1999.

Year	1968	1999
Net area (km^2)	8.1775	3.0455
Area lost on northwestern side (km^2)	Base data	– 6.0895
Area Gained on southeastern side (km^2)	Base data	+ 0.9575
Rate of areal loss (km^2.yr^{-1})	Base data	– 0.1964
Rate of areal gain (km^2.yr^{-1})	Base data	+ 0.0309

Table 2b. Erosion/accretion at Nayachar Island during 1968-1999.

Year	1968	1999
Net area (km^2)	17.9990	74.1464
Area lost on northwestern side (km^2)	Base data	– 1.4250
Area gained on other sides (km^2)	Base data	57.5724
Rate of areal loss (km^2.yr^{-1})	Base data	– 0.0460
Rate of areal gain (km^2.yr^{-1})	Base data	1.8572

1. 1968 (SOI topograpical sheet)

A nearly rhombic-shaped island. The total area of the island was 8.18 km^2 in 1967-1968. Mud flats at the northern, eastern and western parts of the island were observed. The mud flat in the western part was wider than that in the eastern part. A narrow sand flat occurred at the eastern fringe. Mud flat and sand flat are indicating the intertidal zone. The area was estimated on the basis of the high water and low water line as indicated on the topographical map.

Palms, conifers and bamboo plantations were common on the island. There were also some local waters and springs and narrow tidal inlets.

2. 1995 (Field visit and satellite imagery)

The total area was reduced considerably. The western mud flat was partially eroded. Here and there narrow sand patches formed local beaches. Mud occurred in narrow stripes in the south and southwest. The high and low water lines marked on satellite imagery data, which were derived from the available data of Kolkata Port Trust and field measurements. The vegetation pattern did not change. Two submerged bars emerged between the Ghoramara & Kakdwip Islands in the Baratala River.

3. 1999 (Field visit and satellite imagery)

The total area of the island has been further reduced to 3.05 km^2 in 1999. The part of the island which was covered with dense vegetation has been strongly reduced. The trend of a movement of the island towards the southeast is continued. Erosion is more pronounced on the entire northwestern bank. One of the two submerged bars recorded in 1995 has emerged as a new island between Ghoramara Island & Kakdwip.

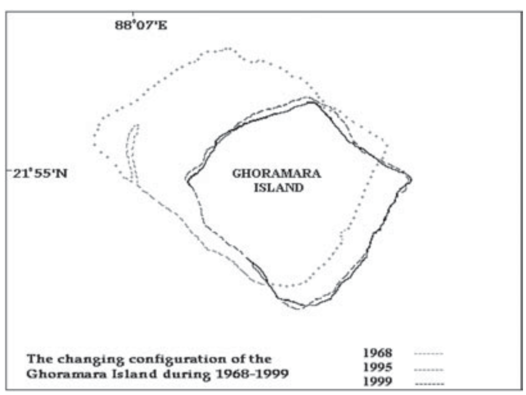

Fig. 2. Time series shoreline changes at Ghoramara Island.

Observations on other islands

It is interesting to observe that while Ghoramara Island is being eroded, another island called Nayachar, located to the northwest of Ghoramara, showed a continuous growth during the same period (Fig. 3). Nayachar Island probably offers a natural protection of the northwestern side of Ghoramara Island from the direct ebb tidal force of the Haldi River. The growth of Nayachar itself may be attributed to a protecting wall constructed by Kolkata Port Trust (India) in the year 1992 (Sanyal et al. 1995). This wall may have been constructed to divert the main flow in the main eastern channel of the River Hooghly (at the southeast side of Nayachar Island) towards the western channel of River Hooghly. Another new island, called Balari Bar, is gradually arising in the River Hooghly, to the north of Nayachar Island (Fig. 4). This indicates that the main tidal force is not working in the western channel of River Hooghly, but rather in the eastern channel.

The southerly flowing River Hooghly has a transverse slope towards the east due to sediment deposits on the western bank as observed from 1999 satellite imagery (Fig. 4), which indicates the main flow/ tidal force does not work to enrich Haldia Port rather it goes towards eastern channel of River Hooghly. A gradual shift of the River Hooghly towards the east (Blasco 1977) also indicates that the main flow touches the northeastern shoreline of Ghoramara Island (Fig. 4). So, the tidal force of the River Hooghly (through the eastern channel), during low tide is directly hitting the northwestern part of Ghoramara Island. It is true that during high tide the southwestern part of the island is hit as well, but the southeastern part is situated in the shadow zone of Sagar Island and the main land of India.

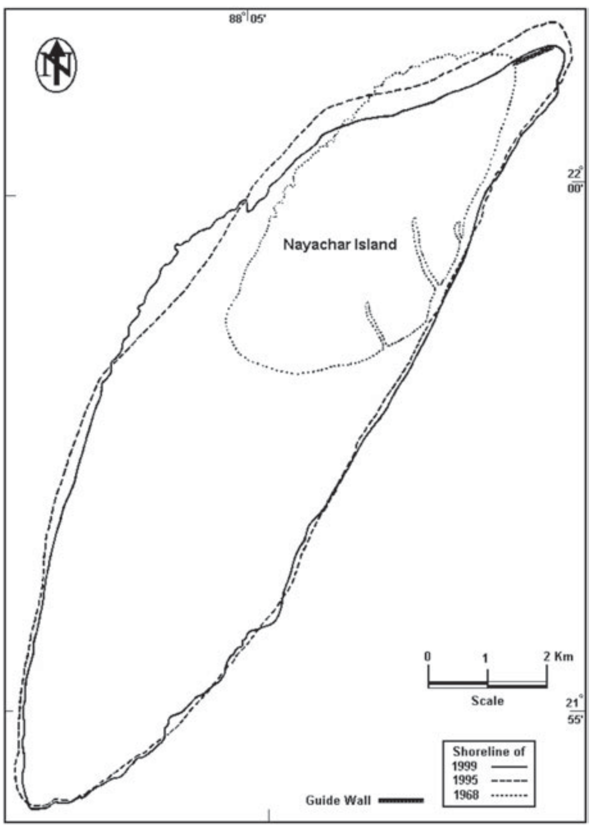

Fig. 3. Changes in the shoreline of Nayachar Island.

Discussion

As shown in Fig. 2, Ghoramara Island is shifting towards the southeast while keeping its shape almost unchanged. Extensive erosion on the northwest part and considerable deposition on the southeast part of the Island have caused this apparent lateral shift of the Island. Table 1 lists the areal changes of Ghoramara Island along with the respective rates of change. The negative sign indicates a reduction in area.

The net loss of area over 27 years (1968-1995) was 4.99 km^2 and the change over four years (1995-1999) was 0.14 km^2. The overall loss over 31 years (1968-1999) was 5.13 km^2. The rate of areal change (taking 1968 as a starting point) up to 1995 was 0.19 km^2/yr; up to 1999 it was 0.17 km^2/yr. The rate of areal reduction in the period before 1995 was higher than in the period between 1995 and 1999, which was calculated to be 0.04 km^2/yr.

The rate of areal loss on the northwestern part over 31 years (1968-1999) was 6.09 km^2 while areal gain on the southeastern part during the same period was 0.96 km^2. Thus, the erosion rate (0.20 km^2/yr) exceeds the accretion rate (0.03 km^2/yr), as presented in Table 2.

The study reveals that from 1968 to 1995 Ghoramara Island lost three villages, and one more between 1995 and 1999. The area gained was less and could not be used immediately for agriculture and human settlement.

At present the estuarine system of the River Hooghly is experiencing strong tidal currents with a low freshwater influx. The geomorphological changes observed on Ghoramara Island are largely resulting from changes in estuarine hydrodynamics which are determined by both natural processes and anthropogenic activities. The island system in the Hooghly estuary, including Ghoramara Island, was stable when the fresh water influx was high. But after the eastward shifting of the course of River Hooghly due to a tectonic uplift (Blasco 1977) the freshwater influx was drastically reduced and the estuary experienced an imbalance in water budget. Even after the construction of the Farakka barrages (1975) the freshwater influx improved only marginally and the normal estuarine dynamics did not return due to absence of seasonal variation.

The protecting wall constructed at Nayachar Island could not divert the main flow towards the western channel of Hooghly River to improve the situation for Haldia Port. It rather prompted sand accumulation in front of Haldia Port. As discussed earlier the tidal flow of River Hooghly during ebb tide directly hits the north-western face of Ghoramara Island with full energy. This may be one reason for the rapid erosion of that part. The material scoured from the northwestern face of Ghoramara Island is carried further offshore by the ebb flow. The tidal force during high tide does not hit Ghoramara Island from the south as it lies in the shadow zone of Sagar Island. The littoral material carried by tidal and ocean currents from offshore may accumulate during high tide. This may have led to the shifting of Ghoramara Island towards the southeast. If this process continues the island will slowly shift towards the main-land and ultimately merge with it; the main flow of River Hooghly (eastern channel) will erode the north-western part of the merged island and ultimately this land will vanish. The southeastern part of Ghoramara Island is moving towards the mainland at a rate of 15 m/yr; at present the total distance is only 350 m. If this process continues linearly then this island will merge with the mainland within 25 years. If the erosion process on the northwestern part of the Island continues at the present rate then the northeastern part of the island will vanish within another 50 years.

The sea level rise is also an important factor forcing the erosion and submergence. The study of sea level changes within the Hooghly-Matla estuarine system revealed that the sea level is rising gradually in the Bay of Bengal at a rate of 2.4 mm/yr (Baksi et al. 2001). This value is slightly higher than the global scenario (2 mm/yr). Sea level rise accelerates the estuarine erosion at the northwestern part of the island, while it acts as a retarding factor to the accretion at the southeastern part. This explains the significant difference between the erosion and accretion rates which results in an overall loss of land.

Remedial measures

The deltaic system of the Hooghly estuary is an ecologically sensitive area (Chaudhury et al. 1994). Therefore traditional constructions using boulders might not be appropriate for the islands here. The nourishment of eroding land with sand, using a sand pumping technique, may be too expensive and may have a negative impact because of the turbulence in the macrotidal estu-

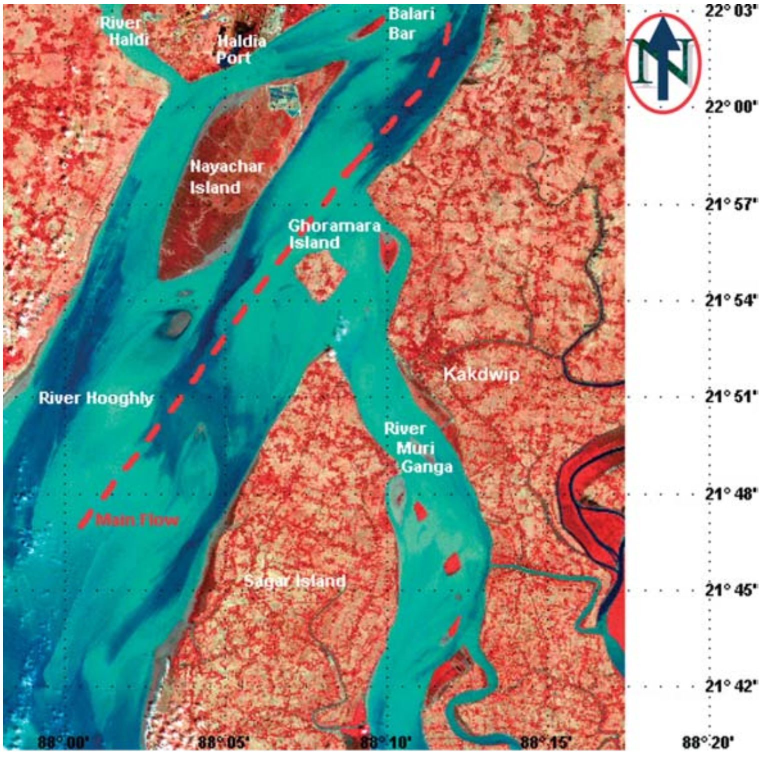

Fig. 4. Probable flow direction in the River Hooghly derived from IRS LISS III 1D data (1999).

ary. Availability of sand sources will also be a problem.

Therefore, a 'bio-engineering' technique has been proposed for the protection of the islands in the Sundarban Delta. This technique includes the planting or sowing of plant species with a rapid development into dense populations. This technique worked well for Nayachar Island in the same delta, which is showing a high growth rate (Fig. 3). In the plantation programme on Nayachar Island species such as *Sonneratia apetela*, *Rhizophora mucronata*, *Excoecaria agallocha* and *Bruguiera gymnorhiza* were considered to be included in the planting scheme. These are all locally available plants and worked very well in context of erosion protection of Nayachar Island. In the case of Ghoramara also the locally available plants and sedges have been considered for its protection from severe erosion.

The dense shrub and tree growth on the banks of water courses not only decreases flow velocities but also influences the distribution of velocities within the river profile (Felkel 1960). The occurrence of woody vegetation on both river banks of natural and undisturbed river courses does not constitute an impediment to the discharge of flood water, because there is enough space in the river corridor to cope with an increased flow (Schiechtl & Stern 1997). Similarly, on Ghoramara, where the mud and sandy flats of the banks have been eroded completely, the vegetated area could withstand coastal erosion.

The mean tidal fluctuation at Sagar Island, adjacent to Ghoramara Island, is 3.0 - 3.5 m. Occasionally the tidal fluctuation at Sagar and Ghoramara may be as much as 7 to 8 m. Since Ghoramara Island is characterized by a meso-tidal regime, away from direct wave attacks, shrubs, willows and reed may be used for the protection of the river bank, this in adaptation to the existing water depth at high tide and the occurrence of exposed wetted slopes of the river bank during low tide (which gets flooded during high tide). These species may be seeded at the time of low tide during the monsoon season. Different types of germinoid species are suitable in relation to the different water depth ranges (Schiechtl & Stern 1997). Table 3 lists some species which can reduce the flow velocity (drag velocity on the river bank face) and can protect the system from topsoil erosion (Felkel 1960). These species (listed in Table 4) may be planted in the intertidal zone of the creek of the island as shown in Fig. 5.

The seeds may be mixed up in the top soil of the river bank. The slopes may be covered by low-cost jute geotextiles pegged at a certain intervals in a grid to avoid topsoil erosion and washout of seeds (Fig. 5). The anchorage of jute geotextiles at both transverse ends may be provided by a wrap-around technique using gravels in the excavated longitudinal trench. Due to high permeability of jute geotextiles pore pressure cannot develop. The surface vegetation will grow within 4-6 weeks. In due course the jute geotextiles will be decomposed but it will not adversely affect the seeding programme because the material will be redundant by that time. The seeds will get sufficient nutrition carried by seawater during high tide.

Shrubs and willows may reduce the drag velocity at river bank faces but may not retard the flood velocity of the river due to tidal effects. The reduction of drag velocity would help to protect the topsoil erosion as well as to reduce the drag and shear forces to the roots of the shrubs and willows. These can withstand flow velocity up to 1.8 m/sec for a prolonged period and up to 4.5 m/sec for shorter periods of time. The permissible drag/tractive force for them is 105 N/m^2 (Linke 1964).

The maximum flood velocity in the estuary is in the order of 3.0 m/sec., while the flood velocity of an average tide is in the order of 2.0 m/sec. to 2.5 m/sec. (Sanyal et. al. 1995). So, the shrubs and willows are suitable for the protection of Ghoramara Island river banks from the tractive force point of view. Precaution should be taken to avoid damage to the geotextiles as well as the shrubs and willows by cattle grazing, animal borrows and human activities.

Other plants such as *Iris sibirica* at ca. 0.0 m to 1.5 m water depth and *Iris pseudacorus*, *Carex rostrata* and *Carex acutiformis* at ca. 0.0 to 2.5 m water depth can also be seeded for shore/ river bank protection of Ghoramara Island. The well adapted seagrass *Porteresia coarctata* may also be applied in the high saline zone and nalgrass (*Phragmitis kakra*) in the low saline zone.

Planting of woody mangals to ensure sediment trapping and the saline grass for protection of topsoil erosion may be adopted above the mean high water line, which gets flooded occasionally with estuarine saline water. The source of sediment may be off shore sand and littoral material carried from tidal river stretch due to strong tidal current. Planting of mangrove species on the land, has to be done sector-wise (Paul 1991 & Banerjee 1998),

Table 3. Characteristics of three graminoid species used for protective planting on Ghoramara Island.

English name	Scientific name	Family name	Required mean water depth from mean High Tide (m)	Season of seeding
Reed canary grass	*Phalaris arundinacea*	Poaceae	0.0 to 0.5	Whole Year
Reed mace or bulrush	*Typha latifolia*	Typhaceae	0.0 to 2.0	Whole Year
Common bulbrush	*Schoenoplectus lacustris*	Cyperaceae	1.0 to 3.5	Whole Year

Table 4. Mangrove plants and graminoids with different characteristics used for the protection of Ghoramara Island.

Mangrove species	Height (m)	Wood volume	Sowing / planting period	Zone of sowing / planting
Avicennia marina	0.5 - 5.0	Medium	July-August	
Avicennia alba	0.5 - 5.0	High	July-August	On the mud flats
Avicennia officinalis	0.5 - 5.0	High	July-August	
Pandanus tectorius	1.5 - 4.0	Medium	September-October	On the coastal sandy region,
Lantana camara	0.5 - 2.0	Medium	May-June	where berm/dunes do not
Opuntea dillenii	0.5 - 2.5	Low	May-June	sufficiently develop.
Calotropis gigantea	1.2 - 2.0	Low	May-June	On the sand berm/dunes,
Ipomoea biloba	0.5 - 1.0	Low	May-June	where vegetation on sand
Launaea sarmentosa	0.2 - 0.5	Low	May-June	berm/dunes do not sufficiently
Cyperus esculentus	0.5 - 1.5	Low	September-October	develop.

according to the slope of the hinterland area, soil salinity and nutrient availability (listed in Table 4). Slope of the hinterland area is very important here, which indicates the duration of submergence of mangrove trees in saline water. In the case of Ghoramara Island the slope of the hinterland is moderate to low (1 in 50 to 1 in 75) away from the river bank. The duration of submergence of mangrove trees in saline water is intermediate on Ghoramara Island.

Mangrove plants such as *Avicennia marina*, *A. alba* and *A. officinalis* may be planted on the mud flats for their further development, which will help to establish forest by natural processes. Drought tolerance plants such as *Opuntia dillenii*, *Lantana camara*, *Pandanus tectorius* etc. may be planted in sandy regions, where the berm/ dunes are not sufficiently developed. *Cyperus esculentus* may be seeded/ planted on the berm, where berm/ dune vegetation has not developed sufficiently.

The wood plantations have to be protected by the Forest Authority from reckless deforestation. Normally the local inhabitants destroy the woody mangrove plants to meet their fuel demand. So, the department has to inform them about the functions of these plants.

Conclusion

The shore protection work using bio-engineering techniques as suggested in this paper can only function properly for Ghoramara Island, if the authorities can provide proper management. The suggested protection measures have to be monitored and replanting may be necessary. Removing selected trees in certain areas may be allowed with a turnaround time of ten years, this for a better management of the mangrove forest. Erosion may be stopped and channel sedimentation may be eliminated. If the depth of the channel can be maintained in this way, the tidal force cannot directly hit the bank of the creek, and erosion of the island may be avoided.

Acknowledgements. The authors are thankful to Prof. A.D. Mukherjee for his continuous encouragement and for his review of the manuscript. They are also indebted to Dr. K.R. Naskar for providing the technical details about the mangroves.

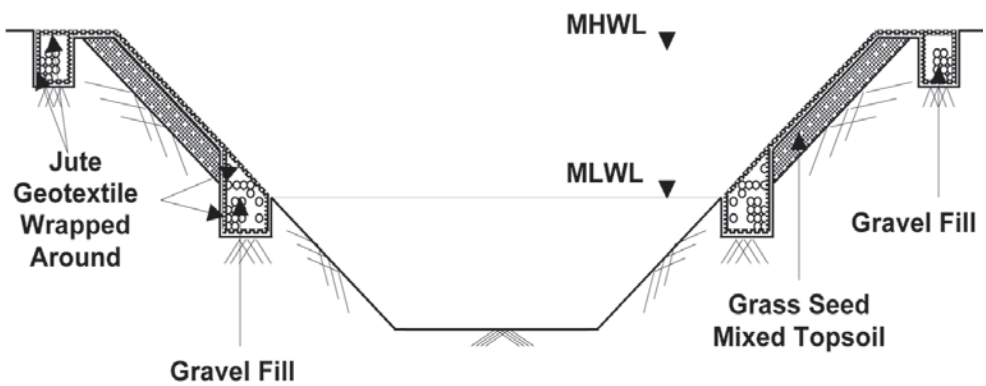

Fig. 5. Layout of jute geotextiles at the sloping riverbank in order to protect the topsoil from erosion.

References

Baksi et al. In prep. *Estimation of relative sea level rise from tide gauge data of Sagar Island, Bay of Bengal*.

Banerjee, M. 1998. Appraisal of trend of coastal zone evolution in the Western Geo-Province of the Bengal Basin in relation to present day coastal zone problem considerations. In: *Proceedings of the National Workshop on Coastal Zone Problems*, pp. 8-35. Jadavpur University, Kolkata, IN.

Blasco, F. 1977. *Outline Ecology, Botany and Forestry on the Mangals of the Indian Sub-continent, Wet Coastal Ecosystem*. Elsevier Scientific, Oxford, UK.

Chaudhury, A. B. & Chaudhury, A. 1994. *Mangroves of the Sundarbans, India, Vol. 1*. International Union for the Conservation of Nature, Bangkok, TH.

Felkel, K. 1960. *Gemessene Abflüsse in Gerinnen mit Weidenbewuchs*. Mitteilungsblatt der Bundesanstalt fur Wasserbau, Karlsruhe, DE.

Ghosh, T. & Sengupta, S.K. 1997. Morphological changes of Ghoramara Island, West Bengal: A documentation. *Indian J. Geogr. Environ.* 2: 64-65.

Linke, H. 1964. Rasenmatten – ein Baustoff zur Ufersicherung. *Wasserwirtschaft-Wassertechnik* 9: 269-270.

Paul, A.K. 1991. Effective management strategies for the coast of West Bengal. *J. Geogr. Rev. India* 53: 60-74.

Sanyal, T. & Chatterjee, A.K. 1995. The Hugly Estuary: A Profile. In: *Proceedings of 'Port of Calcutta'*, pp. 45-51. Calcutta Port Trust, Calcutta, IN.

Schiechtl, H.M. & Stern, R. 1997. *Water bioengineering techniques for watercourse bank and shoreline protection*. Blackwell Science Ltd., Oxford, UK.

Received 29 August 2001;
Revision received 7 August 2003;
Accepted 8 December 2003.
Co-ordinating Editor: W. Ritchie.