Land Use Zoning for Integrated Coastal Zone Management

Md. Shahadat Hossain and C. Kwei Lin

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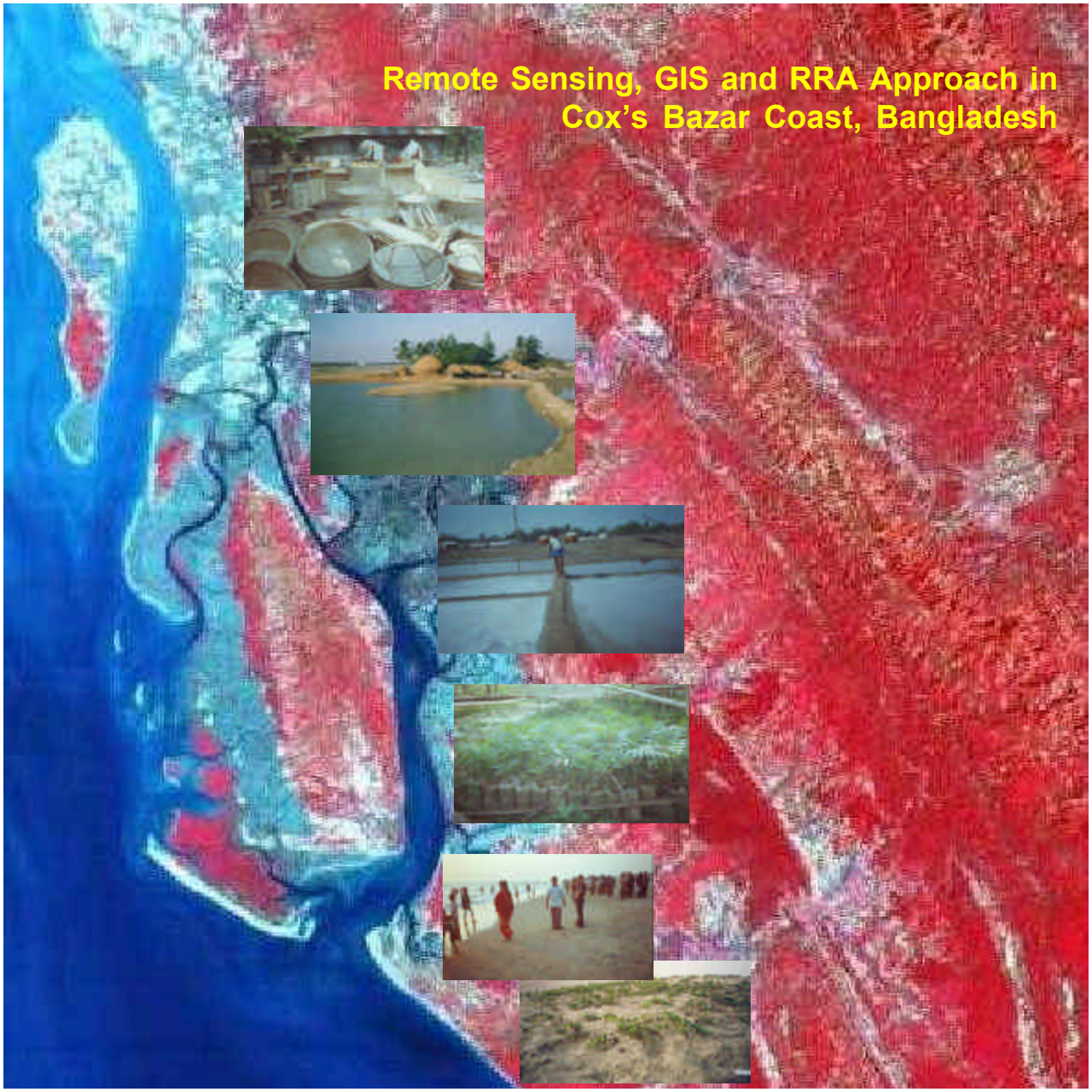

Land Use Zoning for Integrated Coastal Zone Management

Remote Sensing, GIS and RRA Approach in Cox's Bazar Coast, Bangladesh

Md. Shahadat Hossain and C. Kwei Lin

The Integrated Tropical Coastal Zone Management at AIT is an area of specialization under the Schools of Environment, Resources and Development and Civil Engineering. This interdisciplinary field aims to develop human resources for coastal zone management in the Asia and the Pacific regions where the coastal areas encompass a diverse array of resources and ecosystems with intense human activities.

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Introduction

The Cox's Bazar coastal zone has a great importance since pre-historic times for its abundance in natural resources. The local communities have been haphazardly utilizing these resources, resulting in complete destruction of some of them (e.g. Chakaria Sunderban mangrove forest), some being over-utilized (e.g. coastal shrimp farming, natural fish stock) while some other resources remain under-utilized (e.g. molluscs, seaweeds). Due to lack of appropriate guidelines for natural resource conservation and utilization, land use conflicts occur and the coastal zone turned into areas of major conflicts.

Evaluation of existing natural resources is essential for future development. Land/ resource use zoning is needed on the basis of suitable criteria for different activities or mixes of activities such as mangrove afforestation, shrimp farming, salt production, coastal tourism and human settlement for sustainable resource utilization, their conservation and conflict reduction. A main approach here has been to record and assess land suitability classification, to identify land use conflicts considering current land use pattern for land use zoning, and the socio-economic condition of the coastal community. It is suggested that the zoning approach can maximize productivity and improve the socio-economic conditions of the people as well as maintain the ecological balance in the coastal region. The use of remote sensing and GIS techniques are helpful tools to evaluate the existing resources as well as social, economic and environmental condition of the area.

The Earth Summit in Rio in June 1992 was very noticeably oriented towards empowerment through participation and emphasis shifted significantly from the traditional top-down perspective on policy implementation, to one of bottom-up people-led development. It was recognized that sustainable development would require the training and education of all levels of society, where indigenous people and their communities have a vital role in environmental management and development because of their knowledge and traditional practices.

However, Cox's Bazar has not succeeded in involving its communities in coastal resource management. A participatory approach to coastal resource planning can consider the long-term interests of the host community, on whom most of the activities depend. This approach is based on the assumption that coastal management programs will be more successful if local people are involved in planning and implementing coastal policies and programs. Involvement of local people in the management practice would give them a sense to awareness of the resources and ensure their continued livelihood and economic well being. In this way, the coastal zone links ecology with economics, sociology and politics, promoting policies and practices which discourage further degradation, establish priorities, provide incentives for improvement and provide sufficient resources for local people so that they manage themselves willingly.

Zonation in Coastal Zone Management

Coastal natural resources in the Cox's Bazar coast are land, water, fisheries and mangroves, which have been used for multi purposes and have strongly influenced socio-economic development. With the exception of the Cox's Bazar town, which is dominated by service employment in the form of consumer services and tourism, economic activities along the coast are based on the

primary sector: shrimp culture, salt production, fishing and agriculture.

Managing complex systems requires an integrated approach capable of bringing together the multiple, interwoven, overlapping interests of the coastal area in a coordinated and rational manner, harnessing coastal resources for optimum social and economic benefit for present and future generations without prejudicing the resource base itself and maintaining the ecological processes. The spatial development has clearly indicated the suitability classes of the Cox's Bazar coastal zone for different uses. On the basis of the suitability classes, land use zoning needs to be made for better production, conservation and to maintain environmental balance. The interdependence of activities and resources in the coastal area suggests that the sectoral approach to coastal area management can not achieve satisfactory results. An effective management of the coastal and marine resources should be based not only on an analysis of individual activities and their impacts, but also on the combined effects of sectoral activities on each other and on coastal resources.

The present work at Cox's Bazar coast has identified the zones suitable for mangrove afforestation, coastal shrimp farming, salt production and coastal tourism. The stakeholders such as aquaculturist, salt farmer, national and private tour operator, local people, respective government departments, non-government organizations as well as local, national and international experts' knowledge have been considered in this zoning process. The objectives have been defined clearly and the required criteria for different coastal uses have been considered during remote sensing and GIS analysis. What is allowed and what is not allowed is clear in this zoning, and developers can plan accordingly. But no zone can be perfect for a long period, as the coast is a changing environment and conditions may change.

An ICZM Framework for Cox's Bazar Coast

It is clear that the coastal zone of Cox's Bazar has suffered from a large number of management-related problems that have produced poor economic returns and extensive environmental damage. Many of the problems caused could have been avoided if good management practices had been followed. An excellent, comprehensive account of ways to improve coastal zone utilization is provided in the framework that deals with some important processes involved in the Cox's Bazar coastal zone (back cover).

- CZM agency
- Public awareness
- Community participation
- Zoning
- Economic viability and Social acceptability
- Time-sharing

For integrated coastal management, plans have to be formulated, guidelines have to be created, and rules have to be written, implemented, and enforced by the government. A lead agency or organization with full authority on Integrated Coastal Zone Management (ICZM) should be nominated/established including Department of Water Resources, Environment & Forests, Fisheries & Livestock, Shipping, Local Government and Rural Development, Land Revenue, Tourism, and other government and non-government organizations, for environment-friendly coastal resource utilization. The ICZM agency should also be able to recommend measures to mitigate or prevent damage or enhance resource use and would include experts in the fields of environment, fisheries, aquaculture, coastal resource management, tourism, socio-economics, waste management and/or other relevant fields.

It would also include local public/private sector representatives, so that the work will truly address local needs.

Public awareness along the coast is a pre-requisite for proper management of marine and coastal resources. Initially, a multifaceted approach, combining printed materials, audiovisual presentations and face-to-face interaction, is probably the best way to start an education program. Depending on the target audience and budget, a variety of additional options can be employed:mass media (i.e. press, television, radio), exhibitions, tours, training/workshops, supply of promotional materials i.e. T-shirt and informal recreational activities with an education focus.

Successful coastal zone management requires the participation of local people, government authorities, non-government organizations, researchers and investors. The coastal community must be involved in the decision, planning and management processes especially for matters that affect them directly. This participatory approach will reduce conflicts with the local communities that are essential for long-term monitoring, and the community should receive appropriate feedback regarding the outcomes arising from their efforts.

Zoning may be used either as a source of information for potential developers, or as a planning and regulating tool, in which different zones are identified and characterized as meeting certain objectives. Zoning of land and water for certain types of development may help in controlling environmental deterioration, and in avoiding adverse social and environmental interactions. Zoning is an important and powerful tool for coastal planners and has a wide range of specific applications and uses. Where zones are delineated on the basis of site suitability, they can be used:

- as a basis for the communication and exchange of ideas about certain development work;
- to encourage development in the most suitable areas;
- to define areas which may benefit from infrastructure schemes specificly aimed at promoting the development and related activities;
- to provide a focus for research or monitoring on development issues as environmental capacity;
- to define environmental capacity in relation to multiple uses;
- to develop area-based certification or quality;
- as a basis for sectoral EIA (Environmental Impact Assessment) or CBA (Cost Benefit Analysis) related to a particular area.

Selection of suitable sites, methods, and species should take into account both employment opportunities for fishermen and local demands for species that are not provided by capture fisheries. Economic viability and social acceptability of the existing aquaculture practices may be further promoted through increased horizontal and vertical integration within local economics. Aquaculture may stimulate acceptance and support by stakeholders of other local activities if the aquaculture planning has taken sufficient notice of changes in patterns of land and water use and waste disposal, use of agricultural by-products, promotion of local marketing systems, and promotion of locally based processing facilities.

Another method of increasing production without opening up new ponds is time-sharing between salt production and aquaculture. It is feasible to use salt ponds for shrimp culture in the monsoon period when high rainfall makes solar salt production uneconomical along Cox's Bazar coast.

Overview of the Cox's Bazar Coastal Zone

Location and Area

Cox's Bazar district is situated on the southeastern coast of Bangladesh along the northeastern coast of the Bay of Bengal. The geographical location is between latitude 20°30′ and 22° N and longitude 91°45′ and 92°15′ E. The Chittagong Hill Tracts and Myanmar to the east, Bay of Bengal to the west, Chittagong to the north and Bay of Bengal and Myanmar coast to the south surround the Cox's Bazar district. The district has 7 Thanas (sub-district) of which the present study covered 2 Thanas (Figure 1) namely Chakaria and Cox's Bazar Sadar. The coast is rich in both renewable and non-renewable natural resources.

The main economically important coastal resources are fisheries, aquaculture, salt, mangrove forest, land, water and cultural heritage. Due to reduced river flow in the winter, the surface water systems suffer from saline water intrusion, making the resource unsuitable for agricultural and domestic uses. The ground water aquifers in the coastal area are under growing stress of salinization resulting from over-exploitation. Sea level rise and low river flows would substantially contribute to that stress. Winter agriculture in the coastal areas is dependent on ground water. Rural water supply almost entirely depends on fresh water sources.

Considerable areas of the coast have been afforested with mangrove since 1966 with the aim of developing dense mangrove forest as well as a green belt along the coast. The most natural and dynamic features include beach and dunes and both develop parallel to the coast. A long sandy beach of about 145 km runs from Cox's Bazar to Badar Mokam. This stretch offers good tourism and recreational opportunities.

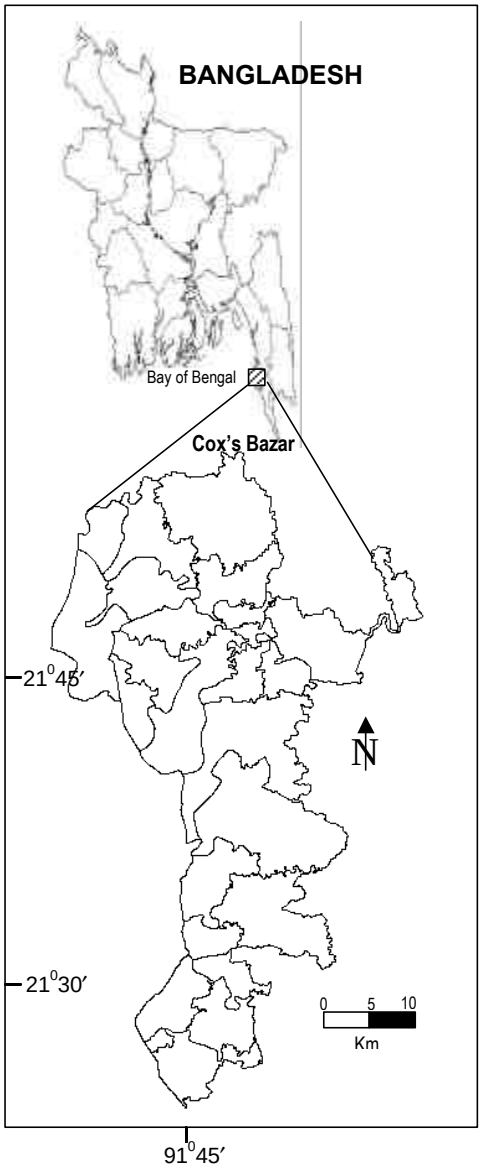


Figure 1. Geographical location of the Cox's Bazar

Climate

The Cox's Bazar coastal zone features a tropical maritime climate. The two major air streams affecting the coast are the southwest monsoon, with winds from southwestern direction and the northeast monsoon, with winds from northeast direction. The southwest monsoon commences in April and lasts till October, which brings air of high humidity from

the Indian Ocean, creating clockwise circulation in the Bay of Bengal and the area receives high rainfall. The northeast monsoon wind blows from the mountain/hill areas, and coastal water forms an anti-clockwise circulation, which begins in November and lasts until next March, the period of the dry season (Annex 1). The dry season can be sub-divided into a cooler dry season from November to February with low temperature foggy weather and a hot dry season from March to May with high temperature and evaporation and periodic thundershowers.

Hydrology

The two major river systems in the area are Matamuhuri and the Baghkhali Rivers, which flow from east to west (Figure 2). These rivers originating from the Chittagong Hill Tracts and Myanmar swell rapidly and flow in spate for a few days at the time after heavy pre-monsoon or monsoon rainfalls in the Chittagong Hill Tracts. Many canals such as, Big Matamuhuri, Small Matamuhuri, Desmia, Pakua, Bhola, Pachacoral, Tetong, Varuakhali, and Fulchari are also important waterways. Besides these, the Moheshkhali and the Kutubdia Channels as well as the Bay of Bengal are also situated in this coast. There are numerous tributaries and micro-channels criss-crossing the coast, particularly the Chakaria Thana. The rivers and canals are influenced by tides and suitable for navigation. The tidal water can reach about 50 km inland and plays an important role in the water supply for shrimp farming and salt production in the Cox's Bazar coastal zone. The mangrove in tidal floodplains comprises an accreted mud flat of low ridges, inter-ridge depressions and shallow basins. Innumerable tidal creeks intersect the landscape. The highly porous soils on the hills and high valleys serve as aquifers to store rainwater enabling continuous seepage supply to feed the streams during the dry season.

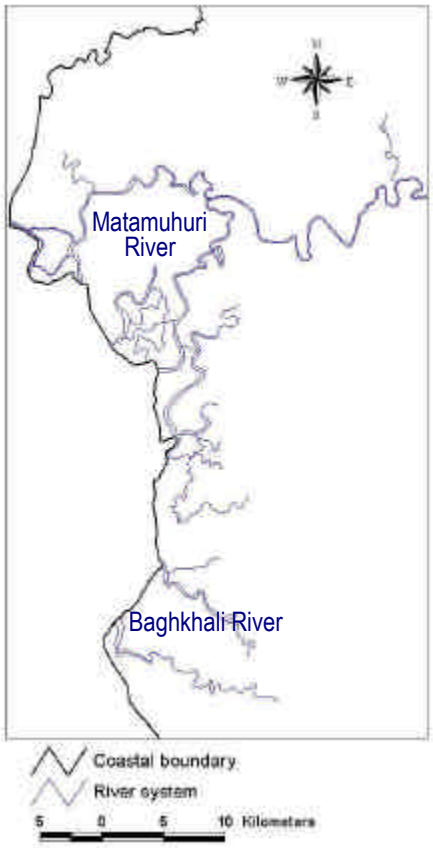


Figure 2. River systems of the study area at Cox's Bazar coast

Physical processes at the coast

In Cox's Bazar coast tides are semi-diurnal with two high and two low waters during a lunar day. Tidal behaviour varies along the coast in terms of magnitude but not of pattern. The tidal range at the Cox' Bazar coast is strong, ranging from 0.07 m at neap tide to 4.42 m at spring tide at Baghkhali river. The main, large scale circulation in the marine water of Bangladesh is of clockwise and anti-clockwise rotation, both created by the wind. The current velocity varies from 4.5 to 5.5 knots during spring tide during the summer monsoon, and 2.3 to 3.9 knots during neap tide. Waves running up the coast often throw large numbers of organisms on to the beach, where they die. Wave height varies from 0 to 9 meters.

The Chakaria Sunderban mangrove forest

The main block of natural mangrove forest in Cox's Bazar coast, the historical Chakaria Sunderbans occupied the low-lying saline swamp at the mouth of the Matamuhuri delta. The swamp consisted of innumerable low-lying islands, which were mostly submerged at high tide.

The present field observations as well as the satellite image (Landsat TM) (Figure 3) revealed that the forest has been completely destroyed (Figure 4). Responsible factors for the destruction of the mangrove forests are the removal of forest products for fuel, high pressure of grazing, haphazard fishing, human settlement, salt production and, probably the worst one, is shrimp farming. In addition, the fishermen used to build dams in the mouth of the creeks and thereby disrupted the tidal inundation causing water stagnation. Due to the hydrological changes, seedlings in stagnant water failed to survive, which seriously affected the recovery of the lost stock [1]. Such interference coupled with the government policy of converting the reserve mangrove forest into shrimp farms and human settlement led to the drastic depletion of the mangrove.

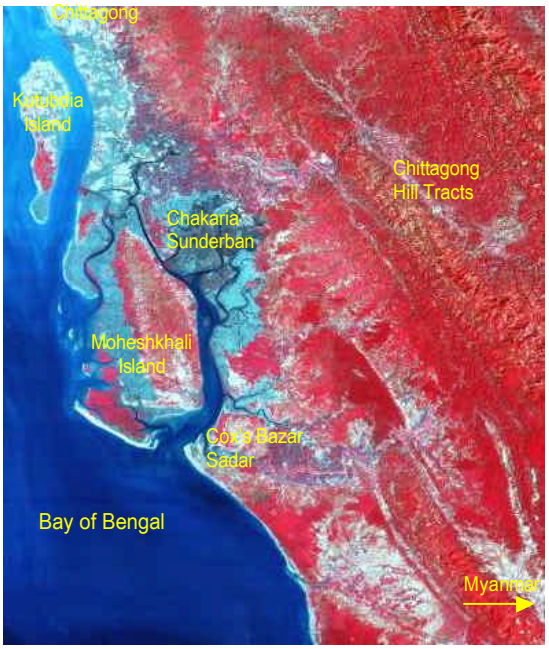


Figure 3. Landsat TM image showing the study area (Cox's Bazar coast)

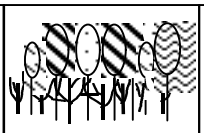
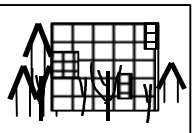
Mangrove status					
Time	**1903**	**1929**	**1952-1975**	**1977-1988**	**2001**
Activity	Reserved Mangrove forest	Allowed human settlement	Human settlement expanded	Shrimp and salt encroachment	The entire mangrove forest altered in shrimp farms with minor salt bed and human settlement

Figure 4. Historical changes of Chakaria Sunderban mangrove forest in Cox's Bazar coast for 100 years time scale

Social Situation and Resource Utilization

Occupation- Daily Activities and Seasonality

The major activities of the people are shrimp farming, agriculture, fishing, salt production, both as daily labour and owner of such businesses. One person may be engaged in two or more different occupations, i.e. shrimp culture, salt-making and agriculture. Some of the occupations are seasonal, so a person can take up different activities in one year. Among the business people, most are engaged in hotels and restaurants, selling of handicrafts and gift items for tourists, and supplying fish, shrimp and salt.

The daily activities of men involve intensive labour for income generation for the family, while women's activities are family-oriented (Figure 5). Most of the men work in agricultural fields, salt beds and shrimp farms as daily labour. They are also engaged in wood cutting, taking care of cattle and trading in the local market. During the fishing period (September to March), fishermen stay 3-7 days at sea depending on the success of the catch. Some of them are engaged in making fishing crafts and gears. The women in coastal communities do not participate directly in income-generating activities. They generally look after their families. The daily chore of childcare, collecting water, fuel, cooking, chicken and duck rearing, homestead gardening, sewing clothes, making handicrafts and occasional enterprises to increase family income is a heavy burden. All these effort are unrecognized and unpaid for. In the Cox's Bazar coast most of the respondents were Muslims and they offer prayers five times a day. These prayers are offered at around dawn (Fazar), at noon (Johore), mid afternoon (Asar),

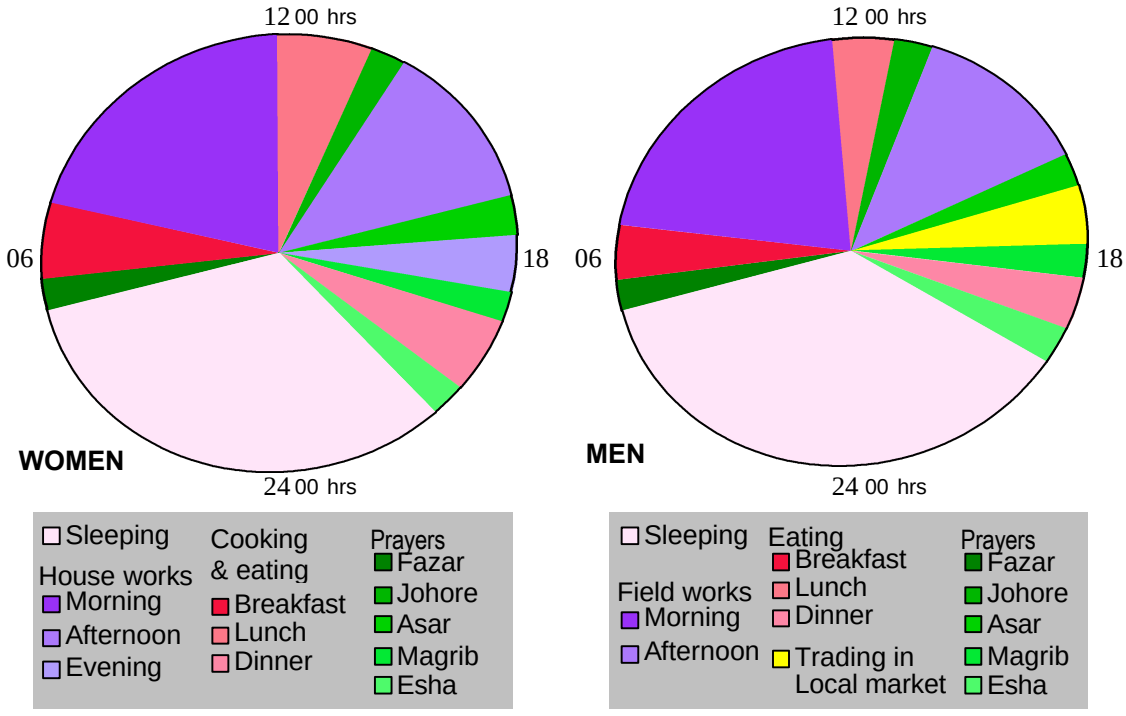


Figure 5.Daily activity charts of men and women along Cox's Bazar coast of Bangladesh

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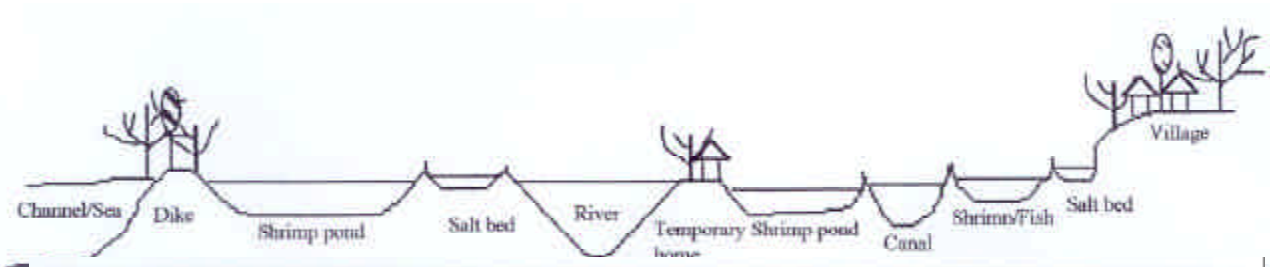


Land use	Channel	Dike	Shrimp	Salt	River	Human	Shrimp	Canal	Shrimp	fish	Human
Resources	Fish, shrimp, oyster, green mussel	Green tree	Shrimp, sea bass, mullet	-	Fish, shrimp, oyster, green mussel	-	Shrimp, sea bass, mullet	Fish, shrimp	Shrimp, eat fish, prawn	-	Tree, livestock
Livelihood	Fishing, shrimp fry		Pond preparation, harvesting	Salt collection	Fishing, shrimp fry		Pond preparation, harvesting	Water supply	Pond preparation, harvesting	Salt collection	Gardening, poultry, agriculture
Problem	Water pollution, siltation, declining fishery production		Mangrove destruction, lack of technology	Mangrove destruction	Water pollution, reduce fishery production	Over-exploitation of natural resources	Mangrove destruction	Water pollution	Mangrove destruction	Mangrove destruction	Lack of drinking water, electricity, transport, education, toilet
Opportunities	Fishing	Shelter	Employment		Fishing, water supply		Employment		Employment		Construction of house, water tank

Figure 6. Transect analysis showing present land use pattern of the Cox's Bazar coast, Chakaria area

after sunset (Magrib) and evening (Esha). Wild shrimp fry collection, which used to be the major income generating activity, has been reduced greatly due to the recent development of hatchery industries along the Cox's Bazar coast. As a result very few men and children were found to collect wild shrimp fry from the rivers, canals, creeks and coastal waters. A seasonal calendar is helpful for documenting regular cyclical periods (i.e. seasonal) and significant events that occur during a year and influence the life of the community. It provides a general picture of important environmental and socio-economic changes during the year (inner back cover, up).

Transect analysis was clearly focused on the existing land use pattern, particularly of the Chakaria area (Figure 6). The transect assisted in concentrating discussions on specific zones and the activities carried out there, and identified some key problems. Among the advantages of transect analysis is the simple portrayal of the resources present and the associated economic, social and environmental issues in spatial terms [2].

Socio-Economic Condition of the Coastal Community

Field visits and group interviews provided some ideas about the socio-economic condition of the local people. Most had been living there for generations. The typical average household size consists of 7 to 8 members in the Cox's Bazar coast, and the houses set up were usually inhabited by the husband and wife, children, brothers, sisters and parents. The area is densely populated with 687 people per square kilometer as of 1998 estimations. More than 90% of the people are Muslims, very few are Hindus while Rhykans are dominant among the tribal groups. Increased population is one of the main factors that caused the depletion of natural resources i.e., mangrove destruction, over exploitation of fisheries resources, etc.

The local people are depending largely on the coastal natural resources for their living, i.e., fishing, farming, agriculture, and trading. All of these factors lead to destruction of the coastal natural resources to meet people's demands.

About 55% of the people in the study area are illiterate, which is related to natural resource destruction. Education creates awareness among the people about the important issues of the society i.e., population pressure, overexploitation of natural resources, degradation of the natural environment, carrying capacity of the environment, etc.

About 20 to 25 years ago local people of Chakaria were dependent upon the mangrove forest. Many household necessities, such as firewood, housing materials, boat making materials, herbal plants for traditional medicines, honey, and other minor products were provided by the Chakaria Sunderban mangrove forest. The area was a very good habitat for different types of birds, mammals, reptiles, amphibians, etc. People used to catch fishes and shrimps from the water bodies inside the mangrove forest. Deforestation of Chakaria Sunderban has affected the socio-economic conditions of more than 90% of the local community of the Chakaria region (inner back cover, below).

The villagers have been using mud stoves for cooking food (Figure 7). They collect some fuel wood from the forest, nearby hills and along roadsides. But most of them (above 90%) buy fuel wood from the market. Presently fuel wood price ranges from Tk. 200 to Tk. 250 per 100 Kg, which was previously (20-25 years ago) Tk. 25 to Tk 50 only. The price increment has badly affected the social life of the local community.

Figure 7. Mud stoves of three chambers and one chamber are used for cooking food in the Cox's Bazar coast

Some villagers have lost their agricultural land due to shrimp farm establishment, which also has significant impact on the socio-economic conditions. About 50% of the local people have changed their previous occupation in the attempt to increase income. Shrimp farming is the main cause of changing occupation. Other reasons are directly related to deforestation. Fishermen have lost their fishing grounds and have been forced to seek some other occupation to earn a living. A similar story can be related to woodcutters. Peasants are facing a lot of trouble in maintaining their cattle and buffaloes.

Stakeholders

Stakeholders are important because they can support and sustain a particular resource. They could be potential partners or threats in managing and developing coastal resources. The stakeholder analysis generates insights into the characteristics of coastal land/resource user groups and their relationships. The primary stakeholders of coastal land/resource utilization in the Cox's Bazar coast are fishermen, shrimp farmers, salt producers, agriculturists and tour operators (Figure 8). Other examples of stakeholders include government agencies, private/business organizations, non-academic organizations, academic or research organizations, religious/ cultural groups and donors.

A Venn diagram was used for illustrating the nature of interactions and relationships between different land/resource user groups.

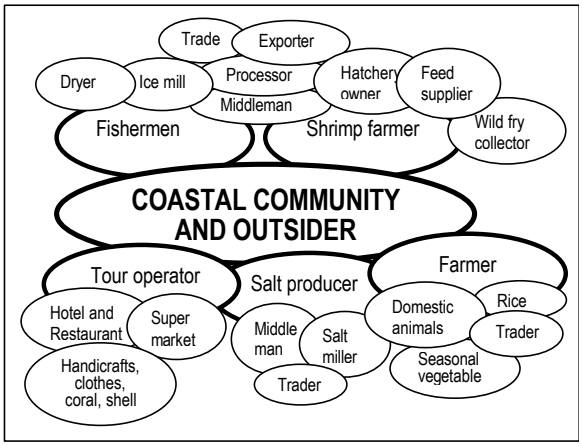


Figure 8. Venn diagram showing relationships among different stakeholders of coastal land/resource utilization in Cox's Bazar

The Venn diagram commonly uses circles to represent groups, where the size of the circle is related to its influence to the whole and the position of a circle relative to other circles shows relationships. The position of the circles relative to a boundary distinguishes internal and external groups.

As an example, compromise may be needed among fisheries, mangrove, agriculture, tourism, salt production and public works where these sectors are all attempting to use the coastal zone simultaneously. Both fisheries and tourism depend to a large extent on a high level of environmental quality, particularly coastal water quality. Both sectors are affected by pollutants, wildlife habitat loss and mangrove forest destruction. In another example, fisheries may require port services similar to those on which tourism depends, an infrastructure system that supplies water, sanitation, transportation and telecommunication. Therefore, planning for both should be integrated with that for transportation and public works sectors.

Land Suitability Pattern and Conflict

Suitability and Conflict

The land suitability maps for mangrove afforestation, shrimp farming and salt beds were overlaid together to distinguish the combined land suitability categories as well as land use conflicts (Figure 9). The most suitable area for individual land uses i.e., salt bed, shrimp farm and mangrove afforestation was found as 5230.72 ha, 3122.46 ha and 1193.04 ha, where the moderately suitable area was 649.98 ha, 1163.61 ha and 1474.65 ha, respectively (Table 1). The land use conflicts among salt, shrimp and mangrove are not prominent because only 0.36 ha was found suitable for these three activities. On the other hand 6.03 ha was found suitable for shrimp and salt, 674.46 ha for mangrove and salt, and 34.65 ha for mangrove and shrimp, which indicate

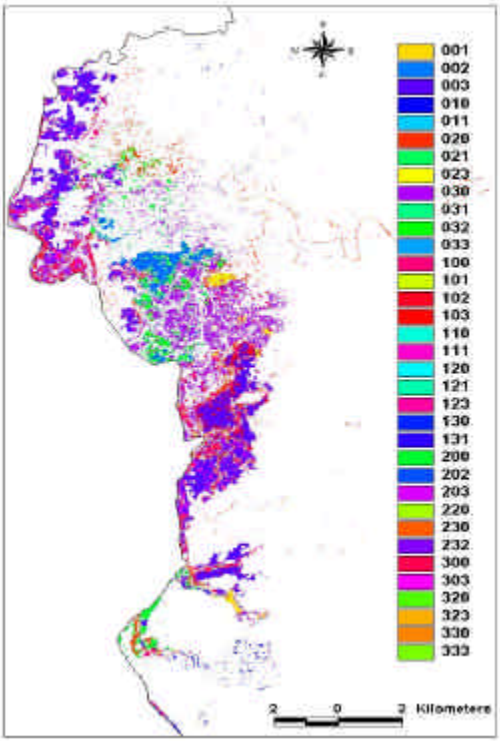


Figure 9. The major categories of land suitability and land use conflicts along the Cox's Bazar coast

conflicts mainly between mangrove and salt as well as mangrove and shrimp. The moderately suitable area for mangrove and salt was 249.12 ha and 21.33 ha for mangrove and shrimp, which also indicates land use conflicts along the coast.

The existing land use map (Figure 10) revealed that most of the suitable areas for mangrove afforestation are currently being used for shrimp and salt production. The present study suggest that the suitable areas parallel to the Moheshkhali Channel have to be used for mangrove afforestation to maintain environmental balance as well as to develop a green belt along the coast, which will act as a protective barrier against the periodic storm surges of the Bay of Bengal to save lives and property. On the other hand, the inner-side areas need to be used for shrimp and salt production on a time-sharing basis that is essential to increase the economic conditions of the coastal community.

Table 1. The major categories of land suitability and land use conflicts in the Cox's Bazar coast (3=most suitable, 2=moderately suitable, 1=not suitable and 0=absence of activity)

Mangrove	Shrimp	Salt	Area (ha)
0	0	2	649.98
0	0	3	5130.72
0	2	0	1163.61
0	3	0	3122.46
0	3	3	6.03
2	0	0	1474.65
2	0	2	249.12
2	2	0	21.33
3	0	0	1193.04
3	0	3	674.46
3	3	0	34.65
3	3	3	0.36
0	0	1	268.29
0	1	0	231.03
1	0	0	1056.15
1	1	1	0.09

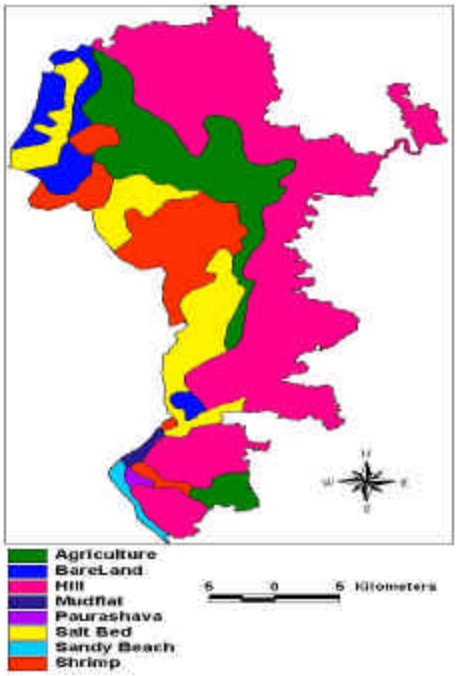


Figure 10. Land use map of the Cox's Bazar coast

Existing Land Use Pattern

The land use map (Figure 10) of the study area [3, 4] was compared with the resulting land suitability map and the potentialities of the categories were analyzed. The result shows that most of the areas of existing shrimp farming, salt bed and coastal tourism activities were developed within the suitable area of the present study. As these activities are being practiced traditionally along the coast for quite a long period, the local people utilize their experience on the local environment and the knowledge gathered from researchers in selecting suitable areas. As a consequence, most of the results of the present study coincide with the existing land use pattern. But the most suitable area for mangrove afforestation is being under-utilized and salt production area utilization is almost optimum, where the suitable area for shrimp farming is tremendously over-utilized causing intrusion of saltwater because of people's interest in shrimp farming other than other activities.

On the other hand, there is informal management for land use zoning with respect to time-sharing i.e.; most of the salt beds are used for extensive shrimp culture with very low stocking density (5,000 to 10,000 postlarvae/ha) during monsoon months (June-November). For this reason the shrimp farming area has been over-estimated by the District Fishery Office relative to the present finding (Table 2).

Table 2. Present result and the existing land use pattern in the Cox's Bazar coast

Land use type	Present finding	Existing land use (Reference)
Mangrove afforestation		718.49 (Coastal Afforestation Division)
Suitable	1929.06	
Moderate suitable	1895.13	
Not suitable	1524.24	
Shrimp farm		15,987.74 (District Fishery Office)
Suitable	3274.74	
Moderate suitable	1256.40	
Not suitable	237.42	
Salt production		8153.27 (Bangladesh Small and Cottage Industries Corporation)
Suitable	6230.16	
Moderate suitable	906.48	
Not suitable	343.17	

Land Use Zoning

The present study suggests that the land should be divided into different zones on the basis of suitability, i.e. most suitable, moderately suitable and unsuitable, for multiple uses. Zoning can be time-shared, i.e. shrimp farming during monsoon months (May to October), and salt production during summer months (November to April). The zoning approach provides important information for potential developers/investors to identify suitable zones for the optimal allocation of resources and minimization of conflicts among users. This will minimize the unplanned horizontal expansion of any activity, particularly shrimp farming or salt production and maximize productivity of smaller areas through vertical integration using modern scientific techniques. This will eventually improve the socio-economic conditions of the people and maintain the ecological balance in the coastal region.

Land Suitability Analysis

Mangrove Afforestation

The Cox's Bazar coast consists of fluvial and tidal geomorphological deposits created from weathered materials from the nearby lands, towering cliffs and mountainous hills and ultimately carried by the Matamuhuri river, the Baghkhali river, the Rezu Khal river and numerous small tributaries and canals. This factor helps in the formation of a newly accreted coastal landscape (locally called 'Char'), which gives an opportunity for mangrove afforestation. The world's biggest mangrove plantations have been established along the coastal belt and offshore islands of Bangladesh. The planted mangrove areas in Bangladesh have been gradually expanding and thus Bangladesh has become a pioneer country in the management of planted mangrove forest.

The spatial development has clearly indicated the location and extent of the accreted mud flat in the Cox's Bazar coast. The diagnostic factors considered for suitability assessment for mangrove plantation are soil type, tidal area, soil pH, soil salinity and land use pattern. The land suitability map was prepared to identify the suitable area for mangrove plantation (Figure 11). The suitable area of 1,929.06 ha was found to be located in the inter-tidal zone of Pokhali, Chaufoldandhi, Badarkhali, Magnama and Rajakhali union. Most of the area is in the stable mudflat along the coast. Soil series of the area are Chakaria, Kutubdia, Badarkhali and Muhuri with silty-loam texture. The moderately suitable area of 1,895.13 ha lies in Pekua, Bheola Manikchar, Paschim Barabheola, Purbo Barabheola and Khuruskul union. The unsuitable area of 1,524.24 ha is scattered mainly in Bharuakhali, Khuntakhali, Dulahazra and Chiringa union due to being outside the intertidal zone as well as multiple land use pattern.

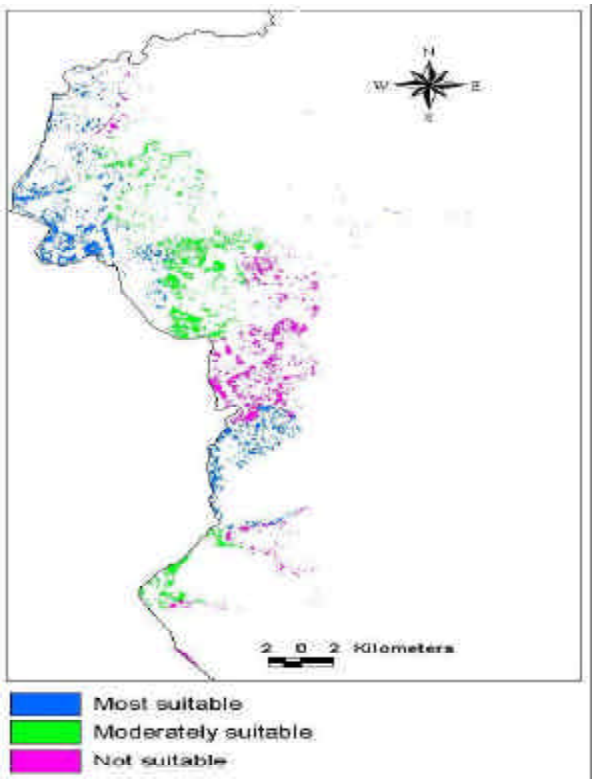


Figure 11. Land suitability map for mangrove afforestation in the Cox's Bazar coast

Timing of plantation depends on seedling period of the mangrove species. *Avicennia* seeds are collected from the previously planted forest during first 15 days of September and directly sown into the coastal land where *Sonneratia* seeds are collected from May to September and reared in the nursery grounds. The seedlings are then planted in the coastal area during calm weather. Maintenance is done for the next three years [5]. Survival rate of mangrove afforestation in the Cox's Bazar coast varies from 10% to 90%. In the first year seedling survival rate is about 10% and in the second year it varies between 80 to 90%. The newly planted seedlings are usually destroyed by siltation and wave action. In undisturbed condition yearly growth varies from 1-2 feet in the 1st year and 5-6 feet in the 3rd year. A

Mostly *Avicennia* species (Figure 12) and some Sonneratia species have been planted in Cox's Bazar coast, as both these species are euryhaline. Salinity of the Cox's Bazar coastal water is usually 30-35‰, but it decreases to 20‰ during May to September due to heavy raining by southwest monsoon. On the other hand, the soil particles are coarse, which is suitable for better aeration and root system development of mangrove species. Three kinds of *Avicennia* species have been planted along the coastal zone of which *Avicennia officinalis* is the tallest with 20-25 m, where *Avicennia alba* and *Avicennia marina* grow up to 10-15 m. *Rhizophora* species like tea-bush with 1-2 m in 20 years along the coastal area of Bangladesh. The *Sonneratia* species are selected for the area of high accretion because this species has the peculiar characteristic of developing the root system at the changing silt levels.

Figure 12. Mangrove plantation in the Cox's Bazar coast

considerable area of planted mangrove forest has been destroyed due to natural calamity as well as salt and shrimp farm encroachment along the Cox's Bazar coast.

Shrimp Farming

Most of the shrimp farms in the Cox's Bazar coast have been established after the-mid 1980's because of large demand and high price of shrimp in the international market. Government leases the coastal land for shrimp farming (Table 3) for a period of 10 years. The farmers have been practicing extensive or traditional farming with a production rate of 230 kg/ha (Table 4). The destruction of mangroves in the Chakaria area had no apparent effect on the shrimp yield. However, there has been no analysis of the amount and cost of alternative artificial inputs into the system such as feed, fertilizer, lime, drugs, human resources and other factors. These costs are usually high, while the natural inputs into the mangrove are free of cost.

Table 3. Year-wise land leasing for shrimp farming in Cox's Bazar coast (Source: Department of Land Revenue, Cox's Bazar, 2001)

Leasing year	No. of cases	Area (ha)
1985-86	181	1,739.65
1986-87	186	1,306.06
1987-88	663	2,569.13
1988-89	1	4.05
1989-90	5	20.24
1990-91	1	12.96
1991-92	1	12.15
1994-95	1	20.24
1995-96	126	650.25
2000-01	278	*809.72
Leased to Dept. of Fisheries		2,834.00
Total	1,443	9,978.45

*Proposal under consideration for leasing

Table 4. Thana-wise shrimp farming area and production in Cox's Bazar coast (source: District Fishery Office, Cox's Bazar, 2001)

Name of thana	Number of farms	Area (ha)	Production (Kg/ha)
Cox's Bazar Sadar	236	3,435.00	230
Chakaria	1,048	12,552.74	
Moheshkhali	309	9,664.20	
Ramu	22	62.69	
Ukhia	105	1,011.34	
Teknaf	44	2,275.05	
Kutubdia	20	130.06	
Total	1784	29,131.08	

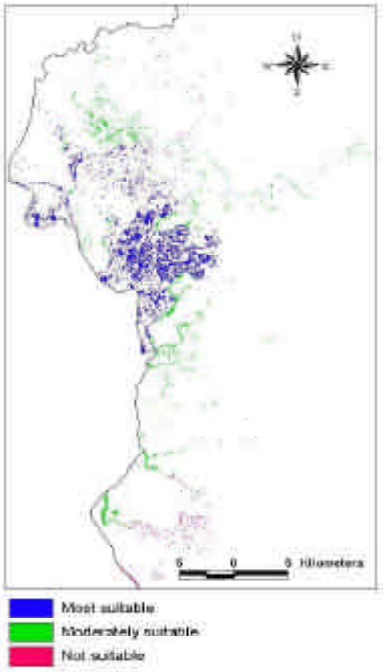


Figure 13. Land suitability map for shrimp farm establishment in the Cox's Bazar coast

The diagnostic factors considered for suitability assessment for establishing shrimp farms are slope, elevation, soil texture, soil pH, organic matter, tidal area and disease problems. The land suitability map has been prepared to identify the suitable area for shrimp farming (Figure 13).

The most suitable area of 3,224.74 ha was found to be located in Purba Barabheola, Paschim Barabheola, Sahar bil, Bheola Manikchar and the western part of Dulahazra union, which is mainly identical to the mangrove-cleared region of the Chakaria Sunderban and characterized by many canals, micro-channels and tributaries of the Matamuhuri river. A small portion is located in Magnama and Badarkhali union. The area is occupied by the Matamuhuri tidal flood plain with a rather gentle slope. The major soil series are Kutubdia, Chiringa and Chakaria with

sandy-loam texture and regular tidal inundation. Land use of the adjacent area is mainly extensive shrimp farms with minor solar salt beds and human settlements (Figure 14).

The moderately suitable area of 1,256.40 ha lies in Pekua, Barbakia, Chiringa, Khutakhali, Chofuldandi and Khuruskul union. Most of the area in this category are located along the rivers, canals and tributaries with slight to moderate slope. The Baghkhali river and adjacent canal was contaminated with disease due to shrimp farm wastes from previously practiced intensive and semi-intensive systems as well as sewage and municipal wastes disposal from the Cox's Bazar town. The unsuitable area of 237.42 ha was scattered throughout the study area with medium slope and somewhat elevated land. The land is some distance from the coast and depends on small canals for water supply and hence faces the problem of water availability. It is surrounded by a hilly area, which does not support any income generating activities for the people and increase expenditure for all sorts of infrastructure development. Shrimp farm development is if electricity, road network and infrastructure are provided, which means more capital investment.

Figure 14. Extensive shrimp farm and human settlement in Cox's Bazar coast

Figure 15. Abandoned shrimp farm has been used for polyculture in Cox's Bazar coast

Some large farms like Grameen Foundation, Beximco Fisheries, Meghna Shrimp Farm, Aquaculture Farms Limited and Allawala Scientific Shrimp Farms practiced semi-intensive and intensive methods during the early 1990's mainly in the Khuruskul area. Khan ***et al.*** [6] obtained 3739-4903 kg/ha from intensive culture of *Penaeus monodon* in earthen ponds at Cox's Bazar. The sudden outbreak of diseases in 1994 led to the bankruptcy of some intensive farms in Khuruskul area. The diseases were caused by pollution, as pond discharge has gone into the Bagkhali river with poor flushing. The major pollutants were organic wastes and nutrients (nitrogen and phosphorus). Fertilizers, cleaning chemicals (e.g. bleach) and antibiotics were also used. The proponents of intensive aquaculture facilities in the Cox's Bazar coastal zone should provide an analysis of the quantity of pollutants to be discharged and their effects on water quality. Presently the Khuruskul area is not suitable for shrimp farming due to disease problems. As a result polyculture of catfish, carp, sex reversed tilapia and *Macrobrachium rosenbergii* have been practiced in the area (Figure 15).

During the group interview one farmer

mentioned that crop rotation and diversification of crops would naturally improve the environmental condition by eliminating the harmful virus due to the absence of required host (here *Penaeus monodon*), and he expected that the area will be favourable for shrimp farming within 2-3 years.

The road communication infrastructure is well developed in the Cox's Bazar coast relative to other coastal areas of Bangladesh. Some parts of the coast have already introduced electricity to facilitate the aquaculture activities. Presently about 45 hatcheries have been established in the Cox's Bazar region, which are able to produce 5000X10^6 *Penaeus monodon* fry/year, more than the national demand (3000-4000X10^6). This will positively protect the wild shrimp fry as well as zooplankton and other smaller marine organisms, which will increase the natural stock of the coastal and marine fisheries. Required numbers of processing plants are located in Cox's Bazar coast, which is a great help for proper processing for the international market. About 10,000 shrimp/fish farmers are working in the Cox's Bazar region, where about 100,000 people are directly involved.

Salt Production

The diagnostic factors considered for suitability assessments for establishing salt farms are soil texture, tidal area and land use pattern. The land suitability map has been prepared to identify the suitable area for salt production (Figure 16.

The suitable area of 6,230.16 ha was found to be located in Pokhali, Chafuldandi, Khuntakhali, Badarkhali, Magnama and Rajakhali unions with the availability of tidal water, and the existing land use includes salt bed and some bare land. The moderately suitable area of 906.48 ha lies in Paschim Barabheola and Purba Barabheola

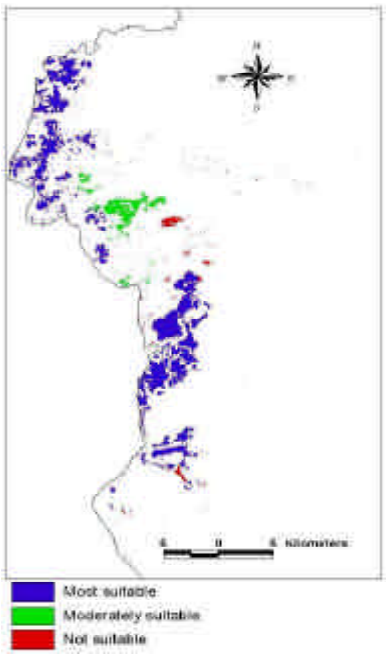


Figure 16. Land suitability map for salt bed establishment in the Cox's Bazar coast

union while the unsuitable area of 343.17 ha is scattered in Chiringa, Dulahazra and Patali machuakhali unions. The area of these suitability classes has been used for other activities, particularly for shrimp farming.

The salt beds are leveled and compacted by using a roller (Figure 17) at the onset of the dry

Figure 17. Roller for leveling and compacting

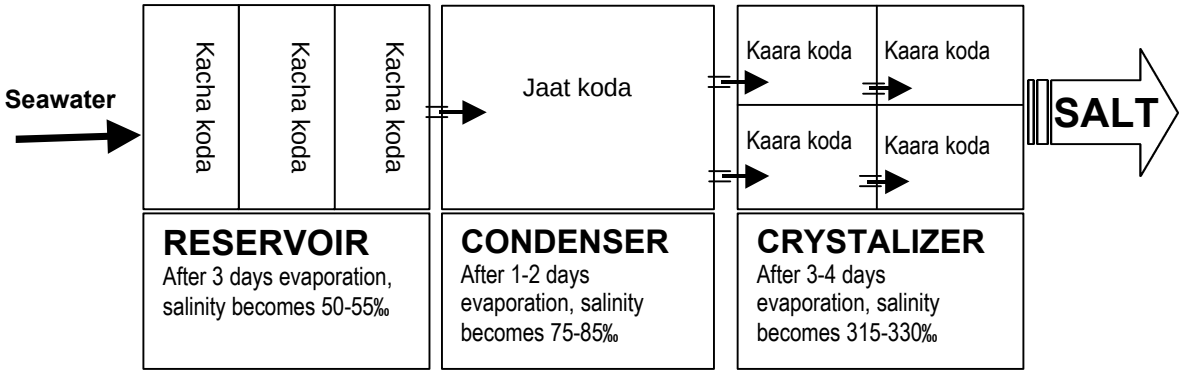


Figure 18. Schematic layout of a typical salt pan by solar evaporation technique in Cox's Bazar coast

season in November-December so that the brine solution will not seep into the soil. Each area is divided into many salt pans such as kacha koda (reservoir), jaat koda (condenser) and bati koda/kaara koda (crystalizer) (Figure 18) by low dikes (locally called ile's) of mud with gradually decreasing size but increasing slope for gravitational transfer of condensed water. Seawater is conducted to the kacha koda through ditches connected with the rivers or canals. If salt pans are lower than high tide, sea water is allowed to flow through gates into them. Otherwise seawater is lifted from the ditches to the pans by manually operated local equipments such as 'dongin' (Figure 19) and 'echuin' (Figure 20).

Figure 19. Dongin for water supply in salt bed

Figure 20. Echuin for water supply in salt bed

About 19,670 ha has been used for salt production along the Cox's Bazar coast under different administrative units, locally called Thana or Upazila (Sub-district) where the present study covers two Thanas (Table 5). Annual average salt production per unit area is 21.50 m ton/ha, which is lower than that of other countries because of short evaporation season and limited mechanization.

Table 5. Salt cultivation area and production in two Thanas at Cox's Bazar coastal district during 1999-2000 (source: BSCIC, Cox's Bazar, 2001)

Name of Thana	No. of Farm	Area (ha)	Production (m ton)	Production rate (m ton/ha)
Cox's Bazar Sadar	102	2,587.77	58,445	22.59
Chakaria	114	5,565.50	116,585	20.95
Total	216	8,153.27	17,5030	21.50

Factors influencing solar salt production in the Cox's Bazar coast

Extended muddy shores with flat and gentle sloping are present along the Moheshkhali channel of the Cox's Bazar coast, especially on the delta and flood plains of Matamuhuri and Baghkhali rivers, where most of the salt pans have been built. The coastal soil is mainly silty-clay-loam that positively influences solar salt production. The critical factor that affects the production of salt is the evaporation rate. Other parameters like temperature, incident radiation, relative humidity, and wind velocity influence the net evaporation of water at different concentrations. A high sunshine rate and air temperature influence the evaporation rate. The hot inland air is beneficial as it improve evaporation. The lower the relative humidity the greater the capacity of the evaporating body to take up more water vapour. Wind helps in the removal of air saturated with water vapour from the surface of the evaporating body and replacing it with fresh unsaturated layers of the atmosphere thus increasing evaporation. However, high wind velocity may blow sand and dust into the salt pans that affect the quality of salt.

The evaporation rate in Cox's Bazar coast varies slightly with the time of year. Minimum evaporation is in May-July when cloudy skies of the rainy season are the rule and the average wind velocity is near a minimum. Evaporation is generally at a maximum in January to April when temperature is high, skies are clear and the windy season is in full progress. The coastal communities have taken full advantages of this seasonal variation to establish a salt evaporation industry. The meteorological parameters are usually favourable for salt production from November to April in the Cox's Bazar coast (Annex 1).

Most of the salt farmers temporarily lease the land for 1 year from landowners or through middlemen, and very few farmers have their own land. The farmers sell the raw salt directly to the traders or some times through the middlemen at the farm gate or in local hat (market). There are about 60 salt processing mills in Cox's Bazar district, where washing, crushing, iodine mixing, drying and packing are done. The UNICEF supplies iodine to the BSCIC (Bangladesh Small and Cottage Industries Corporation) and then BSCIC provides to the mill owners for a token price to make iodide salt. All the concerned departments, organizations and associations are committed to the national government to never supply the salt in the market without iodine mixing. During processing about 25% of the raw salt are wastes, while the remaining 75% are crushed and packed as iodide-salt that is distributed throughout the country mainly for human consumption.

The high salinity waste materials are discharged into the nearby water body, which deteriorates the water and soil quality. As a result numerous species of coastal flora and fauna have been disturbed. About 20 million people are directly or indirectly engaged in salt production and trading in Bangladesh. More than 95% of these are men engaged in production, washing, and trading, where as about 5% are women engaged in packing.

The farm gate price varies between Tk. 80-120/40 kg of salt depending on the quality. The white salt is considered as good quality, while the mud mixed gray salt is considered as lower quality. After washing, crushing and packing the market price varies between Tk. 8-10 per kg. The farmers take loan from the wealthy persons/middlemen on the condition of selling salt at lower price. Market fluctuation is another problem and the main cause is the flooding of salt from the neighbouring Myanmar coast. Myanmar has a huge coastal area along the Bay of Bengal, which is mainly used for

salt production. Near the coast they have high hills/cliffs across which it is very difficult and expensive to supply the salt in their domestic market. So, the producers push the salt illegally to the bordering district (Cox's Bazar) of Bangladesh, even at lower price. Over-production sometimes forms another problem for the farmers. If the environmental parameters are favourable for long periods and the maximum area is taken into cultivation the farmers get maximum production, which may reduce the market price. Some times the middlemen/traders create artificial crisis of money shortage and stop buying. But the farmers need to sell the salts even at a lower price to maintain their daily common demands.

Coastal Tourism

The diagnostic factors considered for suitability assessment for establishing coastal tourism are beach type, tourist accommodation and transportation facilities. The land suitability map has been prepared to identify the most suitable area for tourism development (Figure 21). The sandy beach was found to be the most suitable and the sandy-muddy beach was moderately suitable for coastal tourism development.

Figure 21. Land suitability map for coastal tourism development in the Cox's Bazar coast

The Cox's Bazar is the tourist capital of Bangladesh with miles of golden sands, towering cliffs, surfing waves, rare conch shells, colorful pagodas, Buddhist temples and tribes and delightful seafood. Having the world's longest unbroken (145 km) sandy beach sloping gently down to the blue waters of the Bay of Bengal against the picturesque background of a chain of hill covered with deep green forests, Cox's Bazar is one of the most attractive tourist spots in the world.

The beach is good for bathing, sunbathing and swimming (Figure 22). The breath-taking beauty of the sun setting behind the waves of the sea is captivating. Visits to the fascinating picnic spot at Himchari, Teknaf, southernmost

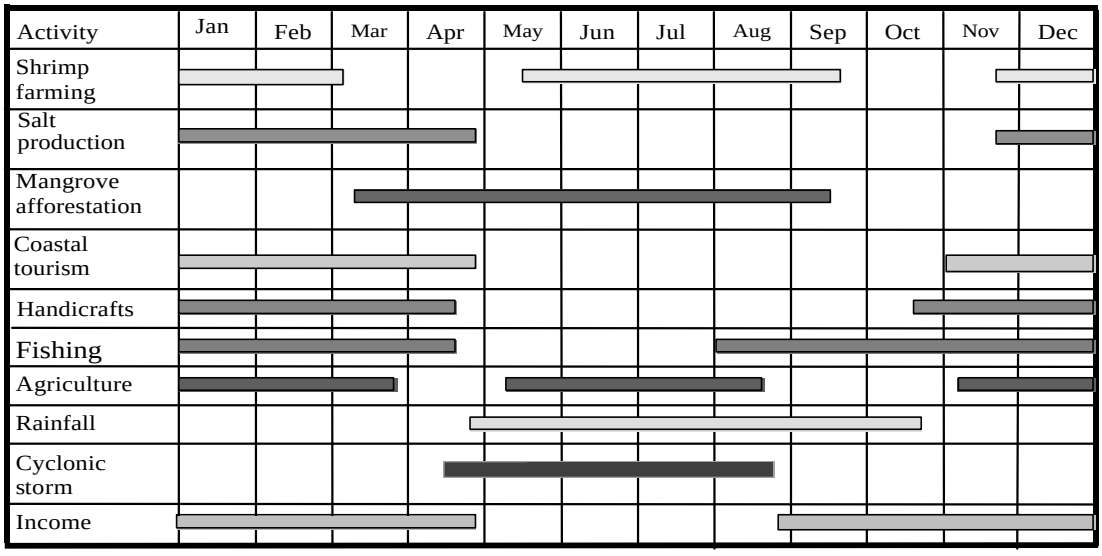
Figure 22. Cox's Bazar sandy beach is a major tourist attraction and source of income for communities

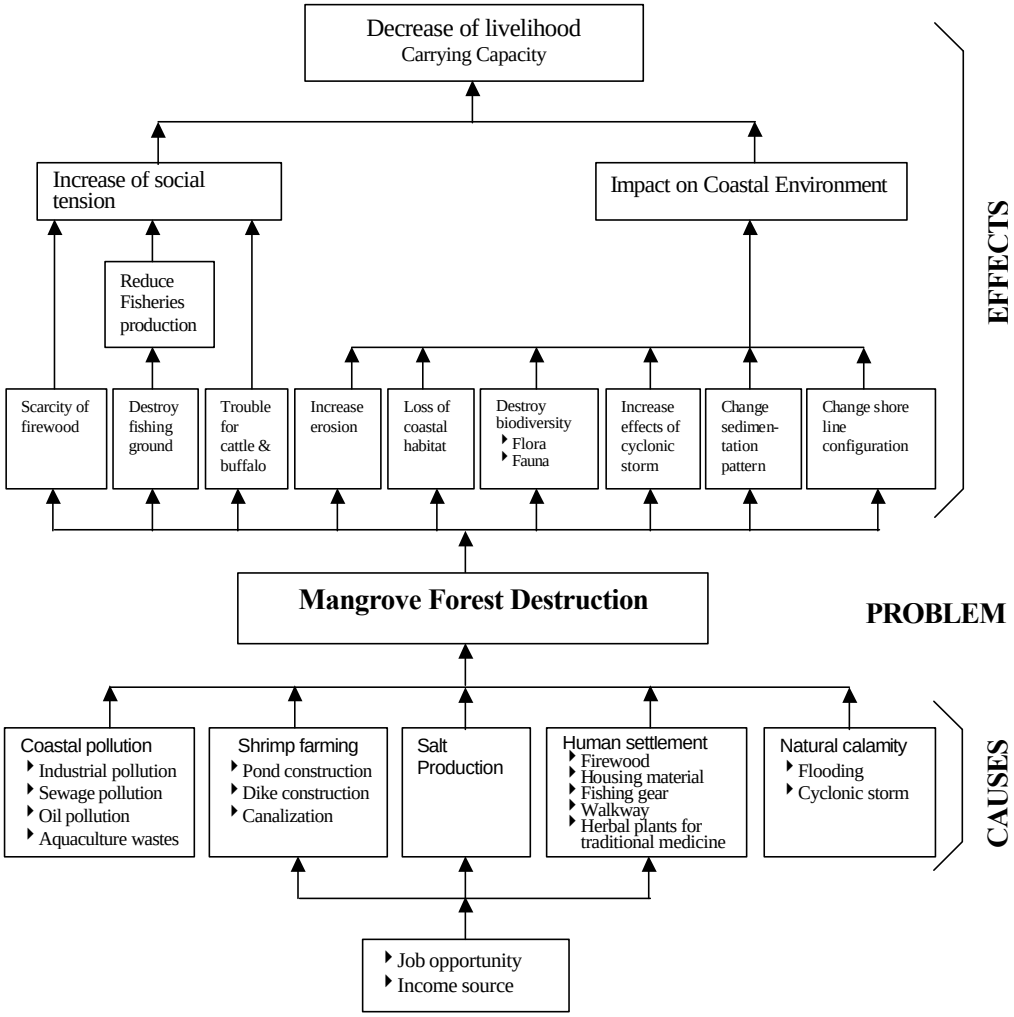
Annex

Annex 1. Month-wise meteorological paramets of Cox's Bazar district (source: Bangladesh Meteorological Department, Cox's Bazar)

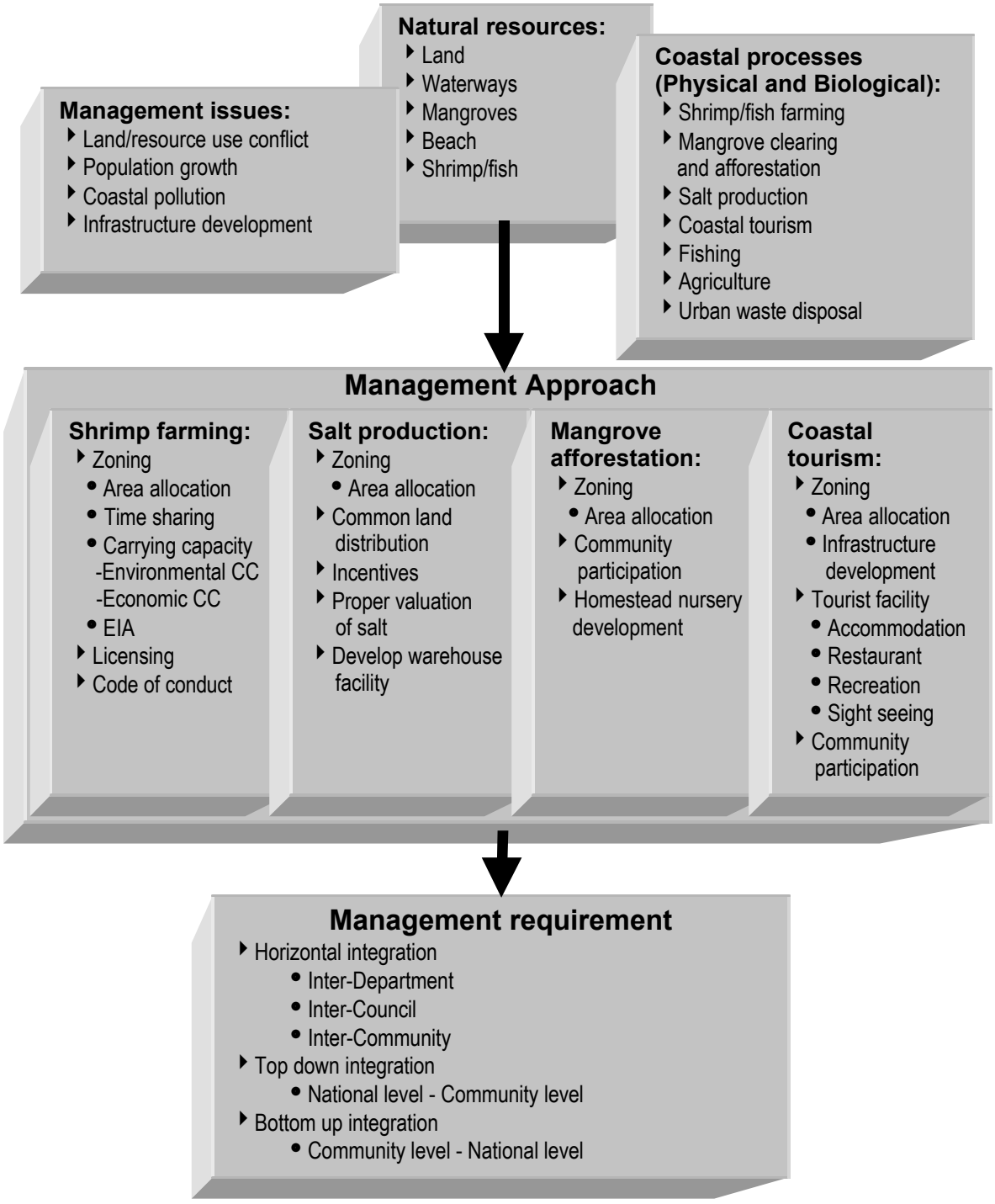
Month (2000)	Total rainfall (mm)	Rainy days	Average temperature (^{o}c)		Rate of evaporation mm/day	R/H at 1200 UTC (%)	Bright sun shine (hr)
			Maximum	Minimum			
January	001	02	27.7	15.7	3.09	67	-
February	002	02	29.1	17.6	3.72	61	-
March	96	04	27.8	21.2	3.59	67	-
April	81	08	33.1	24.1	5.32	75	-
May	573	22	31.8	23.8	2.82	81	182.6
June	841	27	31.8	25.0	2.82	87	127.2
July	1,326	24	31.2	24.6	1.98	87	136.5
August	914	24	31.3	25.1	3.35	86	180.7
September	337	20	30.6	25.0	3.52	86	167.0
October	394	14	32.4	24.6	3.62	81	228.6
November	16	2	31.8	20.4	2.73	75	296.6
December	Nil	Nil	28.2	15.6	2.49	77	314.1

Annex 2. Seasonal calendar showing different coastal activities in the Cox's Bazar





Annex 3. Problem tree analysis for mangrove forest destruction in Cox's Bazar coast



Annex 4. An ICZM framework for coastal zone management in Cox's Bazar

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