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Natural and traditional defense mechanisms to reduce climate risks in coastal zones of Bangladesh

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ABSTRACT

Substantially resourceful and densely populated coastal zones of Bangladesh experience numerous extreme events linked to hydro-meteorological processes viz. cyclones, tidal surges, floods, salinity intrusion and erosion etc. These hazards give rise to extensive damage to property and loss of lives every year. Further, anthropogenic activities in the coastal zones are accentuating environmental degradation causing widespread suffering. Cyclones and tornadoes in particular damage infrastructures and crops every year affecting the economy of the country negatively. Some naturally adapted plants as well as landscapes usually reduce the speed of cyclones and tornadoes and thus, protect the coastal zones. However, human activities have destroyed many of the forests and landscapes. Sundarbans and Chokoria Sundarbans mangrove forests of Bangladesh are under a great threat of extinction due to illicit logging and agricultural expansion. At least 34 plant species of tropical forest are on the verge of extinction. Many animals e.g., cats, bears, porcupines, wild boars, pythons and anteaters are in the process of being wiped out from the coastal areas. Among the marine and coastal species, Red crabs, jelly-fish, sharks, and dolphins are also rare but these were the major species prior to 1980s. This study revealed that during the recent decades there has been massive plantations and construction of embankment and polderization but these and other measures have been found to be impractical and ineffective in reducing disasters in coastal areas. There is a need for integration of traditional coping practices and wisdoms with modern approaches. Available knowledge on some of these traditional practices has been documented for establishing a sustainable policy for management of coastal zones of Bangladesh. By combining traditional and scientific management of coastal ecosystem with mangroves and other plants following triple-tier mechanism and habitat, it is possible to reduce the effects of natural and climate change-induced disasters. Under such a management system, the entire coastal zone can be made more productive and sustainable.

1. Introduction

In South Asia, Bangladesh is the most densely populated delta of the Ganges–Brahmaputra–Meghna (GBM) basin. Most of the country is the flood-plain of the GBM river systems with their tributaries and distributaries. The fertile alluvial flood-plain is characterized by gently undulated landscape with hills and hillocks in the north, east; a central undulated red soil terrace, the Madhupur Tract; and a huge coastal zone with highly fertile land, rivers, estuaries, mangroves, seashore and islands adjacent to the land-water interface of the southern part of the country. The coastal zone comprises 19 administrative districts that have a great diversity of natural resources including coastal fisheries, forests, salt, and minerals, as well as high potential for exploration of both onshore and offshore natural gas. It harbors ports, tourism facilities, and other development opportunities (Michel and Pandya, 2010). Although Bangladesh is most vulnerable to frequent hydro-meteorological hazards such as floods, cyclones and droughts, historically people had developed coping mechanisms including the use of traditional practices for making their homes and homesteads resilient to floods, tornadoes and erosion etc.; climatic-season-based cropping, fish-farming and developed major transportation by boat. They applied traditional knowledge for agriculture, floodplain management and used natural and traditional defense mechanism etc. However, over the last few decades,

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along with the increased frequencies of climate change disasters, increased urbanization, unplanned road construction, industrialization and population growth, many aspects of traditional life have been changing very fast (Nagaraju, 2012; Raygorodetsky, 2013).

Coastal zone communities in different parts of the world, have long before conventional western practices were introduced, relied on their traditional knowledge to reduce disaster risks. Recent human history contains examples of entire islands rendered uninhabitable through environmental destruction owing to external causes; small island developing states (SIDs) are fully aware about the environmental consequences of ill-conceived development with catastrophic effects. Unsustainable development threatens the livelihood and the cultures they nurture; deforestation, coral reef deterioration, habitat degradation and loss, and the introduction of certain non-indigenous species are the most significant causes of the loss of biodiversity and endemism in SIDs which cause fragility of island ecosystems. However, an improved capacity to tap local knowledge and to develop environmentally sound endogenous technologies is also an important step towards sustainable development in a number of areas, including agriculture, agricultural processing, construction, communications and the marine sciences (UNEP, 1994; GDRC, 2014; FAO, 2014).

Traditional customs and management structures are still strong in many coastal communities throughout Timor-Leste. Traditional natural resource management schemes have been weakened by centuries of suppression by Portuguese colonization and Indonesian occupation. Development, modernization, and education have been influencing coastal communities and further weakened traditional coastal resource management; the younger generation is losing such valuable local and traditional knowledge. There is an urgent need to collect and record information on traditions and customs to avoid loss of indigenous culture and heritage that can also serve as model for sustainable use of natural resources (Wever, 2008).

However, Bangladesh is recognized globally as most vulnerable to climate change extremes (Climate Change Cell, 2007). About 80% of the country is deltaic floodplain of the GBM with many rivers flowing from the central India, Himalayas, China, Assam, Lusai and Arakan-Burmese ranges and the catchments of the GBM Rivers flowing to the Bay of Bengal through the estuaries (Fig. 1). Bangladesh is the most vulnerable country in the world to tropical cyclones and the sixth most vulnerable to floods (Government of Bangladesh, 2008). More than 68 million people have been directly affected over the last eight years (Vos et al., 2010), and millions of lives and livelihoods are threatened by frequent weather-related disasters. Low-lying lands, coastline areas and floodplains of most part of the country are highly exposed to both disasters and sea level rise, especially in the coastal zones (Global Humanitarian Forum, 2009).

Above the coastal zone, one-third of the country is partially elevated plain-land, which gets flooded temporarily but with the increased population this floodplain has gradually been occupied with expanded homes and townships. Another 44,000 km^2 area consists of wet-bodies which remain wet for most of the time. However, after the 1960s Green Revolution, these wetlands were also destroyed by earth-filling for agricultural expansion especially for High Yielding Variety (HYV) rice developed by International Rice Research Institute (IRRI). Thus the natural systems including forests, wet-bodies and traditionally managed floodplains and coastal ecosystem have been destroyed and the country is facing serious climate change disasters affecting millions every year (Flood Archive, 2004).

Considering the increasing frequencies of climate change disasters, this study was conducted to compile the natural and traditional adaptation practices and the defense mechanisms used by the people of the coastal zone of Bangladesh to reduce vulnerability to hydro-meteorological hazards and to find out sustainable coping methods which can be integrated in the national or regional policy.

During the study, hazards and degradation in coastal zone, traditional disaster risk reduction measures, mal-adaptation practices and disasters and purview of policy challenges have been assessed.

2. Methodology

During the study, relevant information was collected from grey and published literatures of different scientific research work. Information was also gathered through organizing local workshops and seminars; attending different regional workshops and conferences; visiting research institutions and meteorological stations. Random interviews of different stakeholders, rural and urban administrative bodies, Non-Government Organizations (NGOs), men and women and youth communities of the coastal region, were conducted. Media sources, folklore and local cultures were another source of information.

The effects of climate variability and change, and vulnerability of natural and human systems in the coastal area were studied. For a cross-scale synthesis and policy recommendation, the traditional practices and coping behaviors were investigated; their efficacies were highlighted and compared with present practices to find out the misfits as well as to integrate the scientific basis of the traditional knowledge regarding natural and artificial defense mechanism followed by the people in this most vulnerable region of the earth for thousands of years.

3. Hazards and degradation in coastal zone

The coastal zone has many resources like fertile land, fishing, mangrove forests, marine and terrestrial biodiversity, scenic beauty, marine resources, meeting point of flora and fauna of fresh and saline water; salt fields, and minerals: Quartzes and Zircon, Uranium etc.; and easy transportation and sailing facilities (Rahman, 2010; DoE, 2013). These have facilitated developments of ports, industries and tourism.

The GBM estuaries in the south; the Karnaphuli, Halda and Sangu rivers and the shoreline of the Arakan ranges in the southeast form a distinct feature of the whole coastal zone of Bangladesh (Fig. 1). It has a difficult coastline with many rivers and distributaries and complex ecology which is affected by natural hazards like cyclone, coastal flooding, tidal surges, erosion, salinity and human related activities. About 50 million people, nearly one-third of the total population of Bangladesh live in the coastal zone (Miyan, 2009; Rahman, 2010). However, some phenomena often create disasters; endanger and disrupt lives and the whole coastal ecosystem. Among these, tropical cyclones and tornadoes, tidal surges and floods, erosion, heavy siltation, and pollution especially from the mega-cities and ports, shrimp hatchery and shrimp farms are the most prominent. Deforestation, over-fishing and cutting of hills for unplanned construction, ship-breaking industries and tourism have accelerated destruction of the ecosystem. Unregulated removal of sand, gravel and pebble deposits from beaches and underwater coastal slopes add to the ongoing threats to the coasts (Banica et al., 2003; Bird, 1979; Rahman, 2011a). More than 34 species of tropical rainforest plants, including *Podocarpus nerifolia* and *Enteda phaseoloids* are facing extinction from the coastal hill forests of Chittagong ranges (Rahman, 2011a,b; Khan et al. 2001; Hossain and Ahmed, 2008; Miyan, 2012). Many

animals such as cats, bear, porcupine, wild boars, pythons and anteater are in the process of being wiped out from the coastal areas. Among the marine and coastal species, Red crabs, jelly-fish, sharks, and dolphins are becoming rare but these were the major species before 1980 (Rahman, 2011a). Coastal resource depletion leads to frequent conflict between users and causes serious socio-economic and cultural problems, such as weakening of the social fabric, marginalization, unemployment and destruction of property by erosion.

3.1. Recent trend of environmental changes and decline of resources

Human pressure, misuse of resources, introduction of inappropriate high input-based agricultural technologies; industrial and agricultural expansion and pollution are the characteristics of recent changes in the coastal zone (Sherbinin et al., 2007). Vulnerabilities in the coastal zone are increasing with accentuations of natural hazards caused by environmental degradation, climate change and human activities including exploitation of mangroves (Rahman, 2010; Scialabba, 1998). Bangladesh has already been affected by land erosion, salinity intrusion (Seal and Baten, 2012) and loss of biodiversity. The potential threats are going to be even stronger in future (Pender, 2008; Wong et al., 2007). Due to climate change effects, the incidences of tropical storms and tidal surges have increased in the coastal belts of Bangladesh, India, Myanmar and Sri Lanka. Since the frequency of cyclones in the Bay of Bengal is about 5 to 6 times the frequency in the Arabian Sea (IMD, 1979), the Bay of Bengal share comes out to be about 5.5%. The breakdown of this 5.5% for the littoral countries of the Bay of Bengal is given in the last row of Table 1. Bangladesh is hit by about 0.93% (~1%) of the world's total tropical storms, India by 3.34%, Myanmar by 0.51%, Sri Lanka by 0.22%, and 0.50% die in the Bay without hitting any country. These numbers were arrived at by considering the 110. However, 9.5% depressions hit Bangladesh (Table 1).

If the world's tropical cyclones with death tolls in excess of 5000 are considered, it is found that 16 out of the 35 such disasters occurred in Bangladesh and 11 in India (Table 1). About 53% of the world deaths from these cyclones took place in Bangladesh and about 23% in India, for a combined total of 76% in these two countries. Bangladesh and India suffer most, although both of them together are hit by only 4.27% of the world storms, Serious and recurring floods have taken place during 2002, 2003, and 2004. Cyclones originating from the Bay of Bengal have been noted to decrease since 1970 but the intensity has increased (Ali, 1999).

The cyclones such as Sidr-2007, Nargis-2008 and Aila-2009 are the typical examples which have caused significant damages to lives and properties of the coastal zones (Table 2) (Dube, 2009).

Withdrawal and diversion of upstream water from the major river systems in the dry monsoon have drastically reduced the freshwater flow. A decrease of about 82% is found in case of the minimum discharges during the dry months in the Ganges only (Afroz and Rahman, 2013). As a result, the salinity has been increased; salinity intrusion affects the coastal agriculture, natural

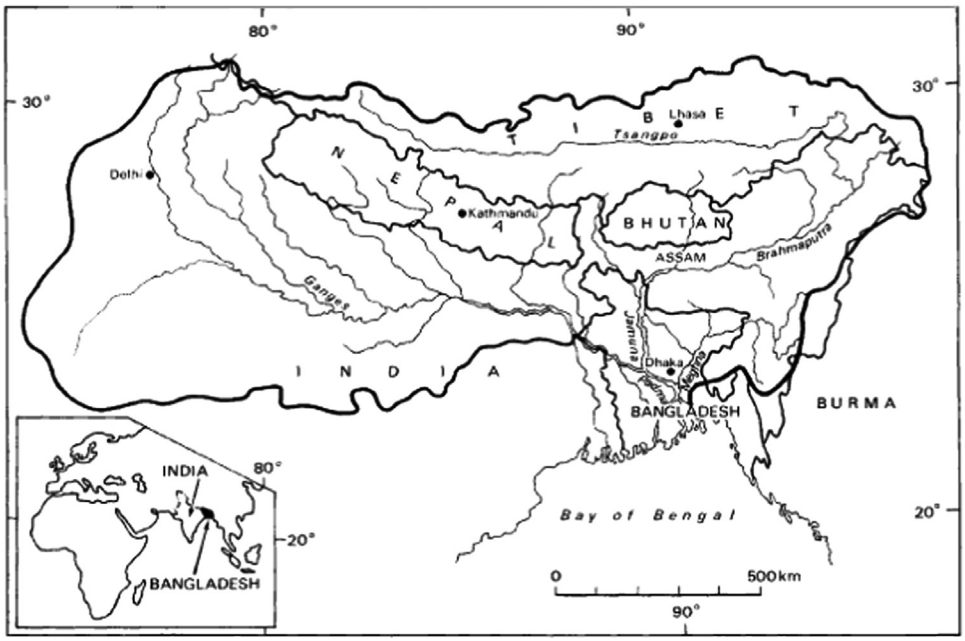

Fig. 1. Catchments of the Ganges–Brahmaputra–Meghna Rivers flowing to the Bay of Bengal. *Source:* Brammer, 1990.

Table 1
Number of cyclones forming in the Bay of Bengal and hitting the littoral countries (1877 to 1995).
Source: Ali, 1999 (modified).

Type	Bangladesh	India	Myanmar	Sri Lanka	Dead	Total
All types	154	848	71	35	115	1223
Depressions	68	539	24	15	69	715
CS (cyclonic storm)	43	197	23	12	35	310
SCS (severe cyclonic storm)	33	112	24	8	11	198
CS+SCS	86	309	47	20	46	508
Percent of global total CS+SCS	0.93	3.34	0.51	0.22	0.50	5.5
Percent depressions	9.5	75.38	3.36	2.1		

Table 2
Tropical cyclones affected coastal zones.

Cyclones	Affected Regions	Wind Speed (km/h)	Death	Damages (million US $) in Bangladesh
Bhola cyclone-1970	Bangladesh, India	205	500,000 (in Bangladesh)	86.4
Bangladesh cylone-1991	Bangladesh	260	138,000	1,500
Sidr-2007	Bangladesh	260	4,036	1,700
Nargis-2008	Myanmar, India, SriLanka, Bangladesh	215	138,366 (126 in Bangladesh)	10,000
Aila-2009	Bangladesh, India	120	325 (26 in Bangladesh)	552.6
Mahasen-2013	Bangladesh	88	17 (in Bangladesh)	200

fish-breeding centers and fresh water supply to the urban and rural areas of the coast. More than two hundred international rivers are carrying waters into Bangladesh from the neighboring countries. Withdrawal of water through upstream dams and embankments has decreased the dry season flow resulting in salinity intrusion which in-turn hampers agriculture in the coastal zone (Bangladesh State of the Environment, 2001). A regional consensus is needed for the share of common water flow.

Coastal populations, including three million inhabitants of the 72 offshore islands are extremely vulnerable. About 18% of households of the southwestern coastal zone are dependent on resources of the Sundarbans, viz. shrimp-fry, honey, Golpata, mollusks, shell, crabs and medicinal plants etc. Because of increasing rough weather in the Bay, nearly 0.5 million people dependent primarily on fishing are in danger by losing their works. Over 160,000 coastal fishermen and 185,000 shrimp-fry collectors involved in marine fisheries are threatened due to cyclonic disasters and tidal surges and reduced fish and aquatic resources (NPDM, 2015). According to a recent study of Soil Research Development Institute (SRDI), Sundarbans has lost 8.3% land (about 50,000 ha) on its northern front due to deforestation for shrimp culture during the period of 2000 to 2010. This destruction has been done by clear-felling of mangrove trees and creating pockets of un-forested areas (The Daily Star, 2013). As a result, these pockets have become low depression zones and more vulnerable to climate-induced cyclones and tidal surges.

3.1.1. *Observed effects of global warming*

According to IPCC, 2007 (AR4), average temperature has registered an increasing trend of about 1 °C in May and 0.5 °C in November during the 14 years period from 1985 to 1998 in Bangladesh. It was also reported that decadal rainfall anomalies are above long-term averages since 1960s (Khan, 2000; Mirza, 2002).

For the Indian monsoon, extreme rain events have an increasing trend between 1901 and 2005 and the trend is much stronger after 1950 (Rajeevan et al., 2008) and widespread increases in heavy precipitation in high elevated Himalayas foothills extending south into the Ganges basin particularly during summer (Roy, 2009) (Figs. 2 and 3).

The annual mean rainfall exhibits increasing trends in Bangladesh (Tables 3 and 4). Decadal rain anomalies are above long term averages since 1960s. Severe and recurring floods have taken place during 2002, 2003, and 2004. The intensity of cyclones originating from the Bay of Bengal has increased since 1970 which caused immense sufferings to lives and destruction of structures and natural resources (Cruz et al., 2007; Sivakumar and Stefanski, 2011).

With the changing climate and withdrawal of water in the upstream, an acute water shortage has impacted badly the rapid urbanization, intense agriculture and population growth. Salt water from the Bay of Bengal is reported to have penetrated more than 100 km in the inland along tributary channels during the dry

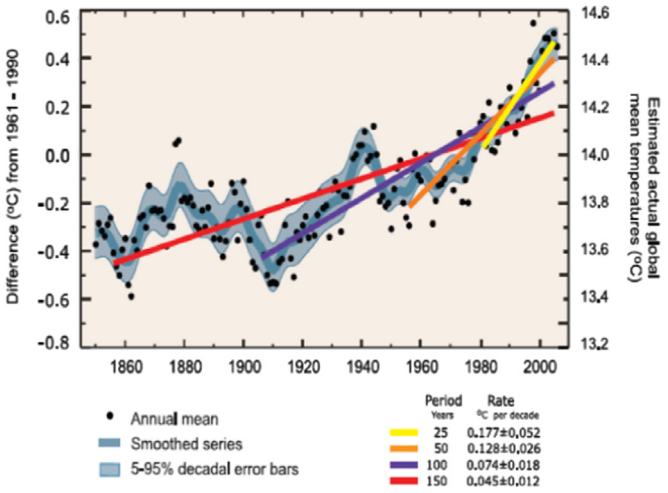

Fig. 2. Rise in temp over 100 years 0.74 °C. Last 50 years decadal rate of rise 0.026 °C but doubles to 0.052 °C in last 25 years (*Source*: DLS, 2013).

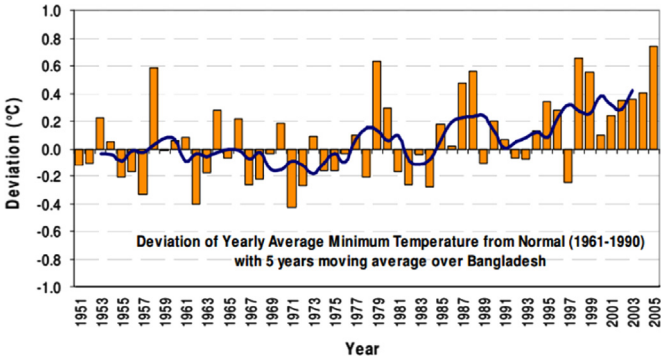

Fig. 3. Deviation of yearly minimum temperature from normal (*Source*: DLS, 2013).

season (Sultana et al., 2008). The precipitation declines and droughts have resulted in drying up of wetlands and severe degradation of ecosystem services (IPCC, 2007). Sea level rise will worsen coastal erosion. In some coastal areas, a 30-cm rise in sea level can result in 45 m of landward retreat (Rabbani et al., 2010a,b). Coastal erosion, cyclones, and storm surges will place coastal infrastructure—housing, industrial facilities, energy and sanitation systems, transportation and communication networks, tourist and cultural sites increasingly at risk (World Bank Report, 2013). In the southern region of Bangladesh it is projected that a 65 cm sea level rise by 2080s, will result in loss of 40% of the productive land. About 20 million people of the coastal area have already been affected by salinity. Rising sea levels and more intensive cyclones and storm surges could intensify the contamination of ground water and surface water causing more diarrhea outbreaks (Rabbani et al., 2010a,b).

Table 3
General circulation models (GCM).
Source: Climate Change Cell, 2009.

Year	Average temperature			Temperature increase			Average precipitation			Precipitation increase		
	Week °C	Month	Ave.	Week °C	Month	Ave.	Week Mm/month	Month	Ave.	Week Mm/month	Month	Ave.
1990	19.9	28.7	25.7	0.0	0.0	0.0	12	418	179	0	0	0
1930	21.4	29.4	27.0	1.3	0.7	1.3	18	465	189	6	47	10
2075	22.0	30.4	28.3	2.1	1.7	2.6	00	530	207	−12	112	28

Table 4
Climate change scenarios for Bangladesh.
Source: Climate Change Cell, 2009.

Year	Temperature change °C mean		Precipitation change % mean		Sea level rise (cm)		
	Monsoon season	Dry monsoon	Monsoon season	Dry monsoon	SMC	NAPA scenario	IPCC 3rd upper range
2030	0.8	1.1	+6.0	−2.0	18	14	14
2050	1.1	1.6	+8.0	−5.0	30	32	32
2100	1.9	2.7	+12.0	−10	60	88	88

3.1.2. Cyclones and tidal surges

Owing to climate change effects the increased climate extremes of tropical cyclones along with tidal surges have severely affected the coastal zone (Table 2).

3.1.3. Floods

About 45.5 million people are exposed to severe and moderate floods like river flood, flash flood and tidal flood. Floods of 1974, 1987, 1988 and 1998 caused death of 30,000, 1657, 2379 and 1000 lives respectively and damaged crops and infrastructures (Climate Change Cell, 2009). Recurring floods during 2002, 2003, and 2004 caused huge damages of crops, structures and road transportation (Flood Archive, 2004; Hossain, 2002). In 2007, flood inundated 32,000 km^2 area twice in July–August and in September and 16 million people were affected in three million households of which 85 thousand houses were totally damaged and more than one million damaged partially.

3.2. Effects of environmental change: Natural and anthropogenic

With the environmental change, agriculture has been suffering from uncertainty, for instance, cropping has been hampered by erratic precipitation patterns mainly of rainfall and effects of floods, droughts, salinity, cyclones and hailstorms. It has been predicted that rice and wheat production will drop by 8% and 32% respectively by 2050 (Bhattacharya et al., 2013) and fisheries are also expected to be impacted negatively.

Increased precipitation brings more water in the catchments which are beyond the drainage capacity, causing damage of infrastructure and drainage congestion in the urban areas due to faulty drainage and insufficient channels (Biswas and Emmelin, 2010). Salinity intrusion hampers irrigation and supply of portable water. Trans-boundary withdrawal of water disrupts hydrological cycle and cause increased rainfall during the pre-monsoon, wet monsoon and post-monsoon in upper catchments and/or within Bangladesh leads to more floods and water-logging; causes more river bank and coastal erosion (Climate Change Cell, 2009; MoEF, 2001; Rahman, 2004a, and b).

However, over the years, considerable investment has been made in disaster management especially for flood control works using government and donors' fund and expertise. These measures have blocked traditional navigation routes and roads and highways have further worsened the situation. Embankments and polderization and unplanned afforestation have impacted negatively the coastal zones. Poor maintenance and inadequate management of the polders have contributed to internal drainage congestion and heavy external siltation. As a result, soil fertility and agriculture production in some areas are declining because of water-logging and increased salinity inside the polders (BWDB, 2013). In 2008, the Institute of Water Modeling (IWM) studied the impact of sea level rise in coastal river of Bangladesh and assessed the change in the tidal characteristics of the surrounding rivers due to sea level rise and its impact on inundation area of the polder. Studies revealed that high water level at the surrounding rivers of polders increases in the range of 30–80 cm for sea level rise of 32 cm and 88 cm respectively and this hampered the smooth drainage of the polders.

Prolonged water-logging affected cropping, thick wind-barriers increase the wind-speed and damaged the structures; uprooted trees damaged buildings, transmission lines, bridges and agricultural crops. However, increased awareness has significantly reduced the death tolls (Rahman, 2011a; Global Humanitarian Forum, 2009).

3.3. Future projections

PRECIS (Providing REgional Climates for Impacts Studies) generated scenarios for Bangladesh and predicted that pre-monsoon rainfall will be reduced but wet monsoon and post-monsoon rainfall will be increased, from 2051 and onwards. Monsoon rainfall will follow higher increasing trend and annual average rainfall will follow an increasing trend. Regarding temperature, monthly average maximum temperature will increase in monsoon period and will decrease in other periods but minimum temperature will increase in all periods. However, annual maximum and minimum temperature will follow an increasing trend (Climate Change Cell, 2009).

Impact on monsoon flooding will be severe and flood duration will be prolonged by significant number of days and inundation area and inundation depth will be increased (Climate Change Cell, 2009). The potential land loss estimated by IPCC is even worse—29,846 km^2 of land will be lost, making 14.8 million people landless by a sea level rise of 1 m. Land loss leads to loss of

agricultural land, loss of homestead, loss of road and other communication infrastructure and above all loss of wide range of biodiversity. The great mangrove forest Sundarbans, the world heritage will be lost and the coastal region as well as the internal territory will be further impacted by the tropical cyclones (Earth Justice ACJP, 2009; IPCC, 2001; OECD Report, 2003).

4. Traditional disaster risk reduction measures

Since the Tropic of Cancer passes through the center of Bangladesh, the country is very prone to tornadoes due to widespread terrestrial wet-bodies all over the country. But the coastal zone is more prone to tornadoes and cyclonic storms (Bangladesh State of the Environment, 2001). The coastal zones have excellent natural defense systems with Arakan hill ranges along Chittagong and Cox's Bazar shoreline, strong windbreaks with hill forests in the eastern coast of the Bay of Bengal. Sea currents, web and tides and upstream fresh water flows play very important roles in enriching the coastal zones of Bangladesh (Rahman, 2010). The Sundarbans is the world's largest Mangrove forests. The National Park of Bangladesh was declared a Tiger Reserve in 1973, UNESCO World Heritage Site. Sundarban Biosphere Reserve was formed in 1989 through a notification for coordinating and integrating diverse activities of conservation, research and training for creating a better situation of harmony between man and environment as a part of Men and Biosphere Programme (MAB) (Sundarban Biosphere Reserve, 2006). Sundarbans' green cover has been standing firm against natural disasters for ages (Chand et al., 2012; The Sundarbans, 1997). The vegetation consists of 64 plant species, that have the capacity to withstand estuarine conditions and saline inundation on account of tidal effects and can face strong winds. Sundri (*Heritiera fomes*), Gewa (*Excoecaria agallocha*), Kankra (*Bruguiera gymnorrhiza*), Passur (*Xylocarpus mekongensis*, *Rhizophora* spp., Sundri (*H. fomes*), Goran (*Ceriops decandra*) and Baen (*Avicennia alba*) are some of the important species. The Sundarbans mangrove forests with triple tier natural protection mechanisms protect the inlands from cyclonic storms originating in the Bay of Bengal (Rahman, 2010; Miyan, 2012). Most of the plant species are adapted to the environment and can protect themselves as well as prevent the mounting wind pressure of the cyclones, and storm surges. Viviparous germination, pneumatophore, stilt roots, buttresses, floating behavior of drupes and pods are some of the unique natural adaptation features of many mangrove species Sanjay and Balaji, 1994. Some trees such as Baen and Sundri are so strong that they can easily resist 11,100 psi load (Sattar and Bhattacharjee, 1987). Tornado-prone zone areas (Fig. 4) have specially adapted growing bamboo clumps which are extremely strong with high elasticity and can easily disband the tornadoes. Therefore, every homestead has bamboo clumps in the west and or north-west sides (Rahman, 2004a,b). Bamboos also protect erosion with their strong anchorage-fibrous root system (Geotech Guideline, 2005). Similarly many palms and nuts also break the wind speed and protect the habitats and the lives from disasters especially, the cyclones and erosion (Bird, 1979). Local communities developed many adaptation techniques, innovations and knowledge to address climatic vulnerability. Rural people, farmers and others developed their location specific knowledge and practices of agriculture, natural resource management, human and animal health care. They know far more about their environment, livelihoods and how their society functions than those from the outside (BARCIK Report, 2013).

The inhabitants of the coastal zone used to adapt and manage the frequent storms and cyclones using their wisdoms usually building their homes on raised floor, low height and surrounded

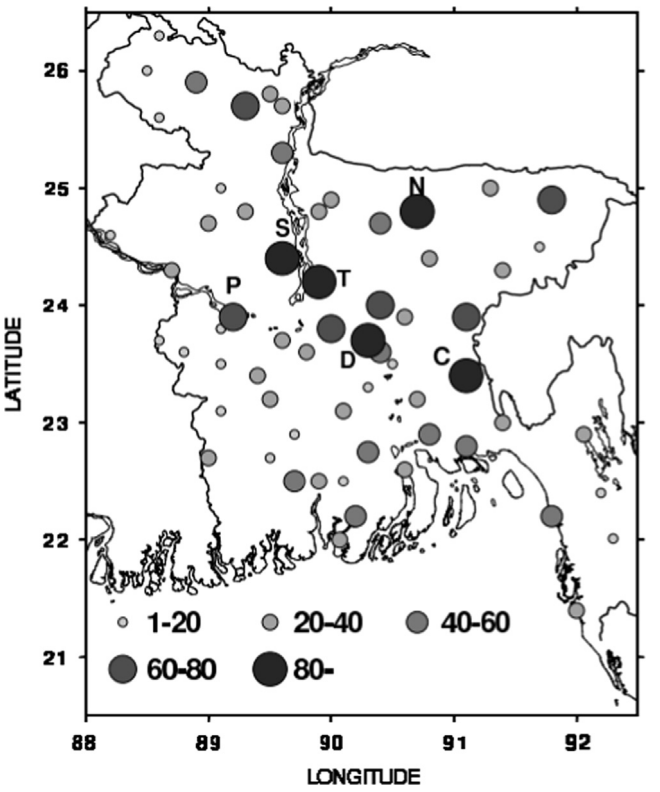

Fig. 4. Geographical distribution of tornadoes in Bangladesh from 1990 to 2005. *Source:* Yamane et al., 2009.

Fig. 5. Homes with windbreaks of the coastal zone.

by highly protective windbreaks with coconut, areca nut and fishtail palm etc. (Fig. 5).

Hill forests of the eastern and northern region and the central Sal forests are the natural defense system used to protect the human habitats from storms and tornadoes, erosion and land-slides Traditionally, the homes of the 1960s or before, people used to choose multipurpose tree and shrubby plants specially to serve the purpose of wind protection, erosion control and habitat restoration in addition to uses for health conscious drinks and foods (Rahman, 2004a,b). Maintaining their appropriate spacing, coconut, areca nut, dates, Palmyra palm, fish-tail palm, Cyperus, and Screw pine are suitable species in this respect, and also offer natural protection to shelter a home from the adverse condition. Palms can withstand 350 km/h wind speed and their specially designed highly elastic leaves can break the wind speed. These plants altogether provide a triple-tier protection measure against tidal surges and strong winds (Rahman, 2009, 2010; Morton, 1988).

The houses of the coastal zone are usually made on wooden platforms on raised earth excavating two or three ponds in each

and every home. The flood plains were nicely conserved by digging deep ponds for multipurpose uses. Excavated earth used to meet the purpose of house building on raised landscape and the houses were designed to face the south to get maximum sunlight (Fig. 5). Large ponds with an area above 1 acre are termed as Dighi; above 10 acres is Sagor and smaller ponds of area less than an acre are called Pukurs which are used as water reservoir for domestic uses, irrigation and swimming and also for fish, shrimps, crabs and duck culture.

The houses of the coastal hilly areas of Chittagong and Chittagong Hill Tracts are traditionally designed with a central king post with suspended roof to protect from the earthquakes. Still in Chittagong and Cox's Bazar, there are Khyangs, the Buddhist temples with traditional king posts usually with large tree trunk erected at the center of the temple for load sharing during the jolting of earthquake. Over thousands of years, people living in various geographical and climatic regions of the world have evolved diverse indigenous regimes of rainwater harvesting and management as an adaptation to climate change. In South Asia, rainwater harvesting has a history of continuous practice over 8000 years and is still used today.

There are other traditional practices e.g. rainwater harvesting and storage in large earthen vats for domestic usages, this practice is a very common one for the coastal island-dwellers (Rahman, 2012). Traditional rainwater collection was very simple and was usually done by tying an old Saree (cloth) or a sheet to four posts in the yard and collecting the water in a traditional earthenware pot, a Motka (Asef et al. 2012).

Among the other traditional practices, people of the coastal zone used to do procure their necessary goods from the Haats and Bazars (markets) during the daytime to avoid the transportation problems at night.

4.1. Traditional landscaping for homes in the floodplains

Typically, rural homesteads follow a courtyard layout. The basic features are: a group of separate structures surround an open space which is defined as the courtyard. Each structure is essentially a one-roomed accommodating different function such as dwelling units for extended family members, kitchens and granaries. Toilets and outhouses such as cowsheds are located on the periphery of the homestead and where recycling of biomass takes place. The layout is introverted, that is, the buildings face away from the outside and are accessed through the courtyard. Entry into the compound from the outside is through gaps between structures. The homestead is extensively planted with trees along the boundary which strengthens the introverted layout. In flood-prone areas, an indigenous practice is to build homesteads on a raised mound, built with earth from the excavation of canals and ponds. Presently, because of resource constraints, it is not always possible for people to raise homesteads adequately above flood level. Planting design and selection of trees is the main aspect of landscaping. Land selection, preparation and homesteads are also part of landscaping. Homestead cropping maintains special adaptation procedure for raising creeper and climber crops on raised mound made with earth boulders to prevent water-logging in the wet monsoon. This is a scientific process to break the capillary system by the air-spaces among the earth-boulders (Rahman, 2004a,b; APDC, 2005; Ahmed, 2006).

Among the other traditional adaptation practices, the season-based cropping to maintain the flora and fauna of soils of dry and wet phases; floating agriculture and deepwater rice cultivation are also important (Word Food Programme). People used to aware of getting the indication of storms and winds watching the mouth of the nests of the weaving birds (Peppler, 2010).

5. Mal-adaptation practices and disasters

Cyclone Gorki-1970, Bangladesh Cyclone-1991, Sidr-2007, Nargis-2008, Aila-2009 and Mohasen-2013 have caused significant damages of life and properties and resources. From the Table 1, it is clear that, Bangladesh has achieved great progress in awareness and minimized the deaths significantly but considering the overall property and resource loss, the proportionate loss is significantly higher in the recent years (BARCIK Report, 2013). It has been observed that, unplanned afforestation, social forestry, shelterbelts, embankments and destruction of mangroves for ship-breaking and shrimp-culture; excavation of shallow ponds pisciculture and so forth are the major causes of increased destruction of properties and resources in the recent years. Huge excavated shallow ponds get heated and create low pressure centres; thus increase the frequencies of local tornadoes and cyclones (Rahman, 2012).

5.1. Conventional methods and policies for reducing calamities

Embankments, polderization, coastal afforestation and shelterbelts, construction of shelter-house are important activities. But in most cases these are constructed against the natural forces, unscientifically and inefficiently. Embankment and polders have caused permanent water-logging in many parts of the coastal zones. Many coastal polders, constructed to protect agricultural land from saltwater inundation, were subsequently turned into large shrimp farms. Saltwater was allowed into the polders in order to raise shrimps. Driven by commercial interests, the land used for agriculture and mangroves was converted, often forcibly to shrimp farming (Haque, 2004) leading to many land-use conflicts (Karim, 2004; Deb, 1998), environmental pollution and social unrest (Firoze, 2003; Rahman, 2011b; and Miyan, 2012).

Shrimp hatcheries pose a great threat to coast line. Cox's Bazar, the world's longest sea beach, is under threat of erosion due to disposal of effluents from the shrimp hatcheries (Fig. 6). Moreover, expansion of the sea beach hotels, motels and recreation zone by cutting shoreline hills has destroyed a great part of the beach which needs immediate attention to prevent further destruction (Rahman, 2010, 2011a; Miyan, 2012). Recently, the government took action to protect the sea beach with sand in jutex bags (Fig. 7).

5.1.1. Coastal green belt

Dense forests can attenuate wave velocity (Mascarenhas, 2006). To protect local, coastal and regional areas from storms, cyclones, tornadoes and tidal upsurges, it is essential to reduce the wind speeds by planting appropriate tree species which can withstand the high speed wind and break the wind speeds. Naturally grown halophytic plants such as Sundri (*Heritiera minor*), Geoa (*E. agallocha*), Goran (*Ceriops* sp.), Kankra (*Bruguiera gymnorhiza*),

Fig. 6. Coastal erosion due to shrimp hatcheries in Cox's Bazar and erosion control measure by sand jutex.

Fig. 7. Coastal erosion due to shrimp hatcheries in Cox's Bazar and erosion control measure by sand jutex.

Fig. 8. Thick windbreaks in the coastal embankments.

Khamo (*Rhizophora mucronata*), Baen (*Avicennia officinalis*), Keora (*Sonneratia apetala*) and Kulsi (*Aegiceros majus*) have the special adaptation for withstanding in the littoral zones with clayey alluvial soil, tides and strong salinity and winds (FAO Corporate Document Repository and Dutta, 1998). There are several palm species for instance, Golpata (*Nipa fruticans*), Hital (*Phoenix paludosa*), coconut (*Cocos nucifera*) and cane (*Calamus tenuis*) and some swamp elephant grasses (*Typha angustata* and *Typha elephantiana*), *Alpinia allughas* and screw pine (*Pandanus facicularis*) have the soil-binding capacity and control erosion. The palms also reduce the speed of tidal upsurges. Moreover, palms maintain a gradual hierarchy and reduce the speed of the strong winds. Most of the palms can withstand winds at a speed more than 250 km/h. Palms can easily break strong wind-flow (Rahman, 2012).

In order to protect life better in coastal areas from cyclones and tidal surges, in 1966 the Forest Department began a mangrove plantation program outside the protective coastal embankments. The program was based on evidence that the Sundarbans natural mangrove forests provided effective protection from wind and waves for the western coastal areas and, thus, it was expected that the plantation of mangrove would give a worthwhile degree of protection to other coastal areas of the country open to the sea. The Coastal Afforestation Scheme had been operated from 1966 to 1974, and established 4745 ha of plantations; the project was extended to 1980, by which time another 29,700 ha were raised. All these plantations were concentrated on the offshore islands and new accretions. The afforestation species were Keora (*S. apetala*), Baen (*A. officinalis*), Kankra (*B. gymnorrhiza*), Golpata (*N. fruticans*) and Gewa (*E. agallocha*). Of late, the coastal green belt has been undergoing indiscriminate destruction and encroachment. A program of participatory mangrove plantation involving nearby coastal communities, which has proved successful in other countries, could be a sustainable mechanism to protect mangrove forests. This mechanism is being actively considered within the Forest Department. However, still there lie problems with the selection of species. It has been noted that the species planted along the coastal embankment are not according to their habit and habitats, on many occasions the damage during the cyclones increased because inappropriate of choice of species (Rahman, 2011a).

Thick shelterbelts on the embankments and along the roads and highways although they protect the coastal zone they also cause adverse effect by increasing wind speed as per Pascal's law which pass through the passages at high speed (Fig. 8). In both Sidr and Aila this effect increased the wind-speed of the cyclones and caused more damages in the interior region especially where shallow water-bodies for shrimp culture were made by removing mangrove forests (Rahman, 2012).

5.2. Wrong selection of species and methods of afforestation

Massive plantation was done without paying attention to the habit and habitats requirements and disrespecting natural adaptation processes. Millions of exotic trees, especially, the *Acacia* spp., Raintree (*Albizia saman*), Mahogany (*Swietenia macrophyla*), Royal Sirish (*Albizia richardiana*) and *Eucalyptus* spp. were planted in the coastal embankments and homesteads replacing the indigenous species. The optimum spacing was not followed during the plantation and the safe distances were not maintained. As the trees are shallow-rooted and in the high water-table zone the root system could not develop for proper anchorage and thus during the cyclonic storms and tornadoes they were uprooted damaging the infrastructures and utilities and crops. The post-Sidr study showed that about 16.84 million woody and fruit trees were uprooted by cyclone Sidr. Haq et al., 2012 claimed that due to raising saplings in the earthen pots the taproot system could not develop which is found to be contradictory in field observations as it is solely an adaptive practice of habit and habitats of the plants (Rahman, 2012). The so-called Sorjan planting system is not a new practice as the people traditionally excavated several ponds in every home for landscaping to make their homes and to grow trees on raised lands.

It was also reported that due to the so-called development of land following Indonesian model ridges and furrows method, the coastal plantations were affected but it was also contradictory to traditional land management by excavating 3 or 4 deep ponds in each house (Rahman, 2012), for hundreds of years back (Figs. 5–7) (Rahman, 2012).

Plants absorb millions of liters of water, everyday and about 95% of water transpire to the atmosphere using 5% only (Verma, 1999; Rahman, 2013a) and thus the plants keeps the atmosphere humid and maintain the hydrological cycle through transpiration and precipitation. Physiological studies revealed that Eucalyptus as a xerophytic plant has a low transpiration rate and controls stomatal opening according to water availability (Kumar, 2004; Brown et al., 2004; Ackerson, 2004; Singh et al., 2004). Similarly comparisons have been done among xerophytic *Acacia auriculiformis, Acacia magium* and native *Pterocarpus indicus* and observed that the stomatal size is almost half in case of *A. auriculuformis and A. mangium* than that of *P. indicus* (Combalicer et al., 2012). Verma (1999) also reported very low transpiration of *Acacia* spp. Significant reduction of stomatal transpiration during dry period in *Eucalyptus* spp, *A. auriculiformis and A. mangium* were reported by many scientists (Whiteheada and Beadleb, 2004; Xiaojing et al., 2008; Rahman et al. 2013; Ali et al., 2009; Lima et al., 2003). Thus it is proved that these exotic species provide less transpiration and impacts upon humidity and low precipitation in the region and thus huge Eucalyptus and Acacia spp. are causing dryness and changing the climate. Moreover, these exotic species do not provide food and shelter for birds and wild-lives and do not favor undergrowths.

5.2.1. Destruction of mangrove forest, hills and hillocks

Since 1980s the mangroves of the South and South-western coast has been indiscriminately destroyed and the land was excavated for shrimp and fishery projects. These shallow large ponds holding saline water raise the local temperature and create pockets for low pressure depression and it is one of the major causes of huge damages of Sidr-2007 and Aila-2009.

The Sitakund mangrove forest has totally been destroyed for ship-breaking yard and caused havoc with pollutants destroying the coastal biodiversity. Due to availability of cheap laborers, the ship-breaking industry is growing very fast in the coastal zone mainly concentrated in Sitakund, Baroawlia, Bhatiari and Kumira, just north of Chittagong city on the Bay of Bengal. Ship-breaking activities present both challenges and opportunities for coastal zone management. In Bangladesh, usually ship-breaking and handling of parts and spares are done manually on open beaches without considering safe and environment-friendly waste management practices although ships contain hazardous materials such as lead, cadmium, organo-tins, arsenic, zinc, chromium, oils, organophosphates and asbestos etc. which cause cancer to lung, skin, intestine, kidney, liver or bladder and damage blood vessels (YPSA, 2005, 2010; Rahman, 2011a).

A ship-breaking activity is a threat to both the terrestrial and marine environment as well as to public health. It is like a mini-version of a city that discharges every kind of pollutants a metropolis can generate like liquid, metal, gaseous and solid pollutants. Oil films on water reduce the exchange of oxygen and carbon dioxide across the air-sea interface which is harmful to aquatic life. Critical concentration of dissolved oxygen (DO) and higher biological oxygen demand (BOD) were found with an abundance of floatable materials: grease balls and oil films in the seawater (UK Essays, 2013). It also causes damage to the bird population by coating their feathers with oil which causes buoyancy and insulation losses. Sometimes spilling may cause wide spread mortality amongst the population of fish, mammals, worms, crabs, mollusks and other water organisms. Furthermore, oil spilling may cause serious damage by reduction of light intensity, inhibiting the exchange of oxygen and carbon dioxide across the air-sea water interface, and by acute toxicity. As a result the growth and abundance of marine organisms especially plankton and fishes may be seriously affected. Indiscriminate expansion of ship-breaking activities poses a real threat to the coastal inter-tidal zone and its habitat (YPSA, 2005, 2010; Rahman, 2011a; Hossain and Ahmed, 2008).

Moreover, cutting of hill and hillocks for industrial establishment in Chittagong is causing a great land area loss and exposure of the rocky strata. Some folded ranges in Cox's Bazar are being cut for residential accommodation. The coast line of Cox's Bazaar has been dug for shrimp-culture which will in the long run make the coastal belt vulnerable to sea current erosion. Hill-cutting may cause land-slides, faults during earth quake.

Unplanned development of resort area after cutting the hills and establishment of shrimp hatcheries along the coast threatens the beach with erosion, while waste from tourists and vendors are damaging the aquatic habitat. About 15 km of the Cox's Bazar beach is at high risk of erosion, especially the shrimp hatcheries at Himchari and Kolatoli, and also motel and hotel zone, and the Diabetic Hospital areas of Kolatoli. Half of the Kolatoli village has already been lost to erosion due to unplanned discharges of water to the sea from 55 shrimp hatcheries (The Daily Ajker Deshbidesh, 2008). Sea current has damaged 3.4 km of beach of the Old Marine Drive Road from Kolatoli to Himchari in Cox's Bazar (Rahman, 2011a).

6. Purview of policy challenges

Despite increasing recognition of the need for Integrated Coastal Zone Management (ICZM) strategies, individual coastal policies in Bangladesh are still mainly formulated with narrow sector-oriented objectives in mind and are not part of an overall framework. Considering the following three reasons the Government of Bangladesh initiated the coastal zone policy in 2005 focusing on the fact that: (a) the coastal zone is lagging behind in socio-economic developments on many aspects; (b) There are poor initiatives to cope with different disasters and gradual deterioration of the environment; (c) the coastal zone has the potential to contribute much to national development.

Under Coastal Zone Policy it is noted that "for a Strategic Planning and Program Development, a Coastal Development Strategy for poverty reduction, economic growth and social development will be formulated and implemented". But the policy documents produced by the government did not consider proper participation of natural resource dependent occupational groups and thus it recommends educating local people on climate change issues as an external matter. In the policy document there is a priority area identified to conduct research on locally adapted crop varieties but it failed to respond to local farmers' knowledge of crop varieties and there is no clear indication of farmers' participation in the research activities. These policy documents are costly to produce yet they end up not being implemented (BARCIK Report, 2013).

The strategy should have a time and resource-bound specification with priority actions in coastal development. It should be about building a process to implement the policies, not preparing a classic master plan. Such a strategy makes critical choices, for example in relation to targeted regions, disadvantaged groups and issues. Focus should be on implementation, including a set of indicators and corresponding monitoring arrangements to assess performance. The strategy document should reflect the specific actions needed to achieve coastal development objectives. In particular, links should be made to the content and process of the National Strategy for Economic Growth and Poverty Reduction and the subsequent multi-year development plans and to other national policy and planning processes. The strategy document should be a component of the chain: Policy $\Rightarrow$ strategy $\Rightarrow$ priority investment Program (Coastal Zone Policy, 2005).

Similarly, although many sectoral policies have clear implications for coastal development, in most cases they do not have specific sections on coastal areas and often fail to capture the distinctive combinations of vulnerabilities and opportunities that characterize the coast. The coast remains an area of institutional weakness (World Bank Report, 2013). Though several government agencies and NGOs are working in the coastal region, there are limited linkages between them and institutional fragmentation is common. Further, many of the government agencies responsible for coastal policies have hardly any presence at the local level. Insufficient coordination—compounded by a lack of institutional, financial, and human capacities for implementation and monitoring impedes effective policy action. Consequently, sectoral development policies, the National Adaptation Programme of Action (NAPA), and the Bangladesh Climate Change Strategy and Action Plan (BCCSAP) all suffer from inadequate execution and follow-up. Too often, policy efforts aim at formulating master plans rather than at creating flexible planning and implementation procedures that can be adapted to changing situations and priorities based on performance monitoring and continuous feedback from stakeholders (Michel and Pandya, 2010). Decisions for policy making and implementation usually go from top to bottom; due to this, various developments of disasters such as cyclone Sidr- 2007 and cyclone Aila- 2009 have been witnessed in Bangladesh. Therefore, a bottom up approach involving the grassroots voice, integration of local and indigenous knowledge should be incorporated to combat hydro-meteorological hazards and other risks (BARCIK Report, 2013).

Practice and experience developed over the years suggest that successful ICZM strategies should be in accordance with nationally accepted criteria for the development of the coastal zone, taking into account poverty alleviation and economic growth, environmental quality, empowerment of local communities and local participation in planning and implementation, disaster preparedness and mitigation, and international cooperation. It should stimulate and facilitate operational interactions among agencies needed to implement sector policies and create a national platform to facilitate implementation and monitor corresponding progress. Most importantly, the scientific values of the traditional knowledge should be evaluated and a comprehensive policy should be made through dialogue between scientists and policy makers.

The key to ICZM is to empower timely decision making at the appropriate levels, providing the flexibility to respond to evolving circumstances and cope with persistent uncertainties. When this has been achieved, the great range of opportunities offered by the coastal zone including marine resources; the accretion of new land, oil and gas resources; the potential productivity of mangroves and other coastal ecosystems; and tourism and leisure activities can be judiciously developed. However, there is inadequate information on pollution and sedimentation loads entering the Bay of Bengal and impacts on coastal habitats and endangered species. This information is necessary in order to understand the functioning of the ecosystem and its reaction to stress over time (NOAA, 2008).

The initiation of the Coastal Zone Policy and ICZM has not contributed any significant improvement rather overall coastal ecosystems have been rapidly deteriorated. The mangroves are diminishing and the effect of cyclones, floods and tidal surges are frequent. The intensity of damages of properties has greatly increased. Both biodiversity and human life have been affected due to lack of scientific information and exclusion of traditional adaptation practices (BARCIK Report, 2013). Bangladesh Resource Centre for Indigenous knowledge (BARCIK) also studied on NAPA and BCCSAP and found that an amount of BDT 3.0 billion (USD 38.46 million) was allocated in 2008–2009 to deal with impacts and adaptation of climate change but nothing was spent during that period. Later, government finalized the BCCSAP in the light of government's Vision 2021 and perspective action plan and allocated BDT 7.0 billion (USD 89.74 million) to Climate Change Fund in 2009–2010 fiscal year. Reports also pointed out that for every project, budget and project design cost has been proposed where more experts in the preparation of details project will also be included for donor hunting as loan or grant. The NAPA document has ignored the communities understanding, their experiences and observations, and the traditional and indigenous knowledge and practices. In every individual project documents, the writing teams have considered to involving several experts, infrastructural constructions, new project formulation but have not addressed how the existing similar projects could be incorporated and coordinated. That actually results in 'action when the disaster starts'. Virtually very little progress has been achieved to mitigate the long-term climate change impacts other than minimizing human death.

The major challenge to ICZM is to realize these potentials while mitigating or adapting to vulnerabilities through a process that enhances the livelihoods of the inhabitants and provides communities with avenues for input to, and support from, external institutions and of course traditional adaptation practices and the natural and traditional defense mechanisms.

For Bangladesh, the political institutional barrier is the largest obstacle to overcome, requiring awareness and capacity building at the highest political and policy levels. Increased funding would help, but must be channeled toward the most climate-vulnerable communities through appropriate structures to maintain accountability and transparency. A coherent, dynamic national action plan is needed to prioritize adaptation measures, regularly review implementation, and eventually revise and reprioritize policy actions. Such a plan should facilitate more comprehensive evaluation of adaptation options, providing a framework for assessing social and environmental as well as economic costs and benefits across all relevant sectors and stakeholders. Formulating this plan would force decision makers to think beyond the short-term, politically expedient horizons of three to five years. A shift to long-term planning will enable the long-term effects of climate change—with predicted rises in sea levels, possible increases in the frequency of major storms, and changes in rainfall patterns over the whole Ganges–Brahmaputra basin—to be taken into account.

For an effective ICZM, natural phenomenon of wind and water flow and the interaction with the adaptation procedures of biological systems must be considered. Protection of coastal lands, forests, shorelines, water-bodies and islands as well as land accretion such as charlands, sand-dunes and reduction of effects of climate extremes especially the tropical cyclones and tidal surges, the laws of hydrodynamics and wind-forces and the interaction of biological adaptations especially of the trees must be considered and utilized for a sustainable coastal zone management.

7. Conclusions

The above synthesis indicates that, the traditional natural and artificial defense mechanisms are vital to protect the flood plains and the whole coastal zones. However, introduction of some impracticable and unsustainable practices have almost destroyed the long-term adapted cultures. The floodplains can be managed by landscaping and planting appropriate species for protection of the structures and lives from natural calamities like cyclones, tornadoes, floods and tidal surges. Hills and wet-bodies are also important natural protection measures and provide adaptation for diverse species. Since coastal zone of Bangladesh is very vulnerable to extreme events, there is no short-cut solution to protect the region from the vulnerability except by investing in natural and traditional defense mechanism. Conventionally, it was tried with many practices like polderization, embankments, dykes and improvement of roads and highways but these are only increasing the sufferings of people and increasing economic loss causing huge migration to the cities. In the name of "Grow More Food", many wet-bodies were filled up with earth but lost the natural catchments for holding surface water and people are now almost dependent on ground water. Thus, severe water crisis has been emerging. Floods too have become frequent damaging huge crops and livelihoods every year. Massive plantation of some of the exotic and xerophytic trees are driving the country towards desertification and tree food and feed crisis thus losing biodiversity. The policy makers, as well as the researchers are required to come up with better practices for an improved coastal zone management. Countries like India, Myanmar, Cambodia and Vietnam where coastal zones are very vulnerable to extreme events need more interaction and integration of the traditional ways of adaptation. The natural and traditional adaptation practices should be evaluated scientifically through habitat research, interaction with communities and in-depth analysis in the workshops and seminars involving stakeholders for a sustainable national and regional policy for coastal zone management.

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