Succession of embankments due to erosion and poor hydrological conditions in river (Courtesy A. A. Danda)

Chapter 2
Sundarbans a Dynamic Ecosystem: An Overview of Opportunities, Threats and Tasks

Shafi Noor Islam

Abstract The Sundarbans, spreading over 10,000 km^2 area, is one of the largest productive deltas in the world, and is located in the Ganges-Brahmaputra-Meghna river basin over parts of Bangladesh and India. The coastal mangrove wetland is playing a potential role in balancing the ecology, community socio-economy, and livelihoods of the community. It is a hotspot of mangrove biodiversity with 373 faunal and 324 floral species. The ecosystem is dynamic, fragile and complex owing to several climate-, soil-, and water- related stress factors. Climate change and several anthropogenic interventions have transformed the natural landscape with significant changes in the social matrix. The salinity intrusion of water is the most sensitive and serious threat for mangrove ecosystem in the coastal region, more in Bangladesh. Since the diversion of Ganges freshwater at Farakka Barrage in India since early 1975, salinity levels have increased drastically in the coastal region in Bangladesh. The reduction of Ganges flow has made disastrous effects on agriculture, fisheries, hydro-morphology, drinking water and mangrove coastal ecosystem. All these factors, individually and collectively, pose serious threats to livelihood and food security for the coastal community in Sundarbans, and what's more, to the ecological balance. E-flow assessment methodologies are discussed in this chapter with reference to attempts made in Bangladesh. It is believed that the present coastal mangrove wetland ecosystem conservation and planning policy is inadequate. In this backdrop, the article suggests in this introductory chapter thrust on future policies for better management, monitoring and conservation of the Sundarbans in a transboundary mode towards improved livelihood.

Keywords Sundarbans mangrove · Wetland · Ecosystem · Biodiversity · Salinity intrusion · Agricultural crop production · Food security · Management and conservation

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2.1 Introduction

The coastal wetlands in Sundarbans, spreading over 10,000 km^2 area across Bangladesh and India, are playing a potential role in ecological balance and local socio-economic improvement. The coastal mangrove is the most dynamic and potential eco-region in the world. The Sundarbans is the largest mangrove forest in the world which has been declared as World Natural Heritage Site (WNHS) by UNESCO in Bangladesh in 1997, and as World Heritage Site in 1987 in the Indian counterpart of the mangrove forest. It is hotspot of biodiversity with 373 faunal and 324 floral species (Milliman et al. 1989; Khan 1993; Hughes et al. 1994; Gopal and Wetzel 1995; Islam and Gnauck 2008). Over 3.5 million coastal people are directly dependent on the Sundarbans heritage site goods and services (Islam and Gnauck 2008, 2009a, b; Islam et al. 2017).

The Sundarbans is the largest unique mangrove ecosystem of the world. The significance of this unique ecosystem is greatly felt due to its unique biota and source of multiple resource bases for the regional economy. The Sundarbans Reserve Forest (SRF) in Bangladesh comprises of 6017 km^2 and in India it encompasses 4000 km^2 area. Within the SRF, there are three wildlife sanctuaries located in the southern part of Bangladesh. The SRF area is recognized as internationally important as the Ramsar Site and as a repository for globally significant biodiversity and dynamic sensitive ecosystem (Richards 1990). Moreover, it has a unique position not only for forestry but also in terms of deltaic landscapes, eco-tourism, culture and heritage. The natural beauty and the universal value of the forest property have given us natural heritage. The importance of the site is its floristic composition, economic uses.

However, it is a dynamic, fragile and complex ecosystem largely influenced by different stress-related factors in the fields of soil, water and climate, further interacting with each other. The anthropogenic interventions in the Sundarbans have transformed natural landscapes through the process of fire, hunting, agriculture, shrimp farming, along with climate change and industrial pollution (Hughes et al. 1994; Gopal and Wetzel 1995; Islam and Gnauck 2008). The present management and conservation strategy is inadequate. Therefore, it is virtual and essential to conserve Sundarbans World Natural Heritage in twenty-first century of interest to both Bangladesh and India. In this backdrop, the article suggests thrust on future policies for better management, monitoring, and conservation of the Sundarbans towards improved livelihood and food security.

2.2 Ecosystem Concept

The ecosystem concept can apply from a micro level to the global scale, and energy is playing a central role in an ecosystem. Energy flows one-way through an ecosystem that is from sunlight to producer, through food chain, and ends up as heat dissipated in the atmosphere. In contrast, natural materials and mineral nutrients either flow one-way or cycle within an ecosystem (Fujimoto 2000). On the other hand, ecologists consider ecosystems to be the basic units of ecology and of the earth's surface. An ecosystem is thus a space where species interact with the physical environment (MEA 2003).

The ecosystems can be defined as a relationship between biotic and abiotic characteristics.

The meaning of ecosystem means the functions of biotic and abiotic factors, like

$$\text{Ecosystem} = f(\text{biotic and abiotic characteristics}) \tag{2.1}$$

or, on the other hand,

$$\text{Ecosystem} = f(\text{s, cl, a, pm, o, mo, r, w, e, t}, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots) \tag{2.2}$$

where, 's' is soil, 'cl' is climate, 'a' is air, 'pm' is parent material, 'o' is organism, 'mo' is microorganism, 'r' is relief of topography, 'w' is water, 'e' is energy, and 't' is time, etc.

The equations (Eqs. 2.1 and 2.2) represent the scientific expressions and understanding of the definition of ecosystem. In Eq. 2.2 the potential elements which ensure the functions, like soil, climate, air, parent material, organism, microorganism, relief of topography, water, energy, or time are the potential factors that characterize an ecosystem in a particular region, and the area, where Sundarbans, the important natural heritage site, represents one such (Miah and Bari 2002). Over and above, the Sundarbans ecosystem is characterized by a very dynamic and complex environment due to the effect of tidal flooding and cyclones (Islam 2003; Erdogan and Kuter 2010), besides various stress-related factors. This, as a consequence, reflects on various species – their population and symbiotic relationships creating an equilibrium at a given time – under continual drift over time.

2.3 Geographical Setting and Dynamics Changes

The Sundarbans stretches over 10,000 km^2 and located at the south-western extreme of Bangladesh and south-east of the state of West Bengal in India (Hussain and Acharya 1994). The area is situated in the Ganges trans-boundary catchment area, and lies between latitude 21° 31′ N and 22° 30′ N and between longitudes 89° E and 90° 18′ E (Katebi 2001). Out of this approximately 70% are lands and 30% are water bodies.

The Ganges-Brahmaputra and Meghna river systems and drainage basin is 1.76 million km^2 in area (Fig. 2.1) (Islam 2006). The Sundarbans stretches from the Hoogly on the west in India to the Meghna, the estuary of the Ganges and

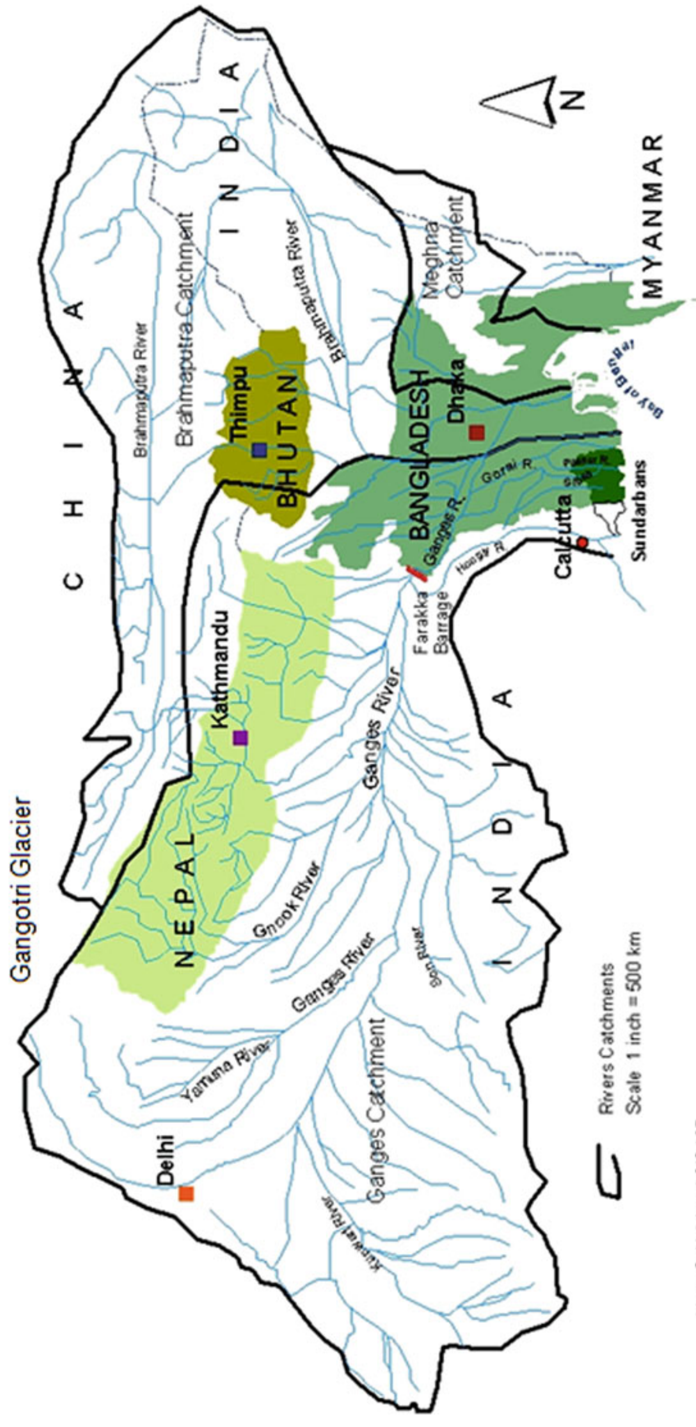

Fig. 2.1 The Geographical location of the Sundarbans in the Ganges-Brahmaputra-Meghna river in the catchment area. (Source: Islam and Gnauck 2008)

Brahmaputra, on the east, located in Bangladesh. It covers the southern portions of the districts, viz. South 24 Parganas in India, to Khulna and Barishal in Bangladesh (Islam 2003). There is evidence to suggest that due to geomorphological processes the Bengal Basin is tilting, diverting fresh water through the Ganges-Brahmaputra river system to the east. It was thus only natural that the eastern part of Bengal was marked by its greater agricultural produce and greater population growth compared to the western part. This was made possible by the silt deposit because of the shift in the river system (Islam and Gnauck 2008; Islam 2016).

The Indian part of the delta is thus being denied fresh water from upstream, resulting in increased salinity (Islam and Gnauck 2008; Islam 2016). The entire region is subject to violent storms, particularly during the monsoon months, as the Bay of Bengal frequently sees the development of cyclonic depressions (Islam and Gnauck 2008) making livelihood fragile and uncertain.

2.4 Characteristic Features

2.4.1 Coastal Geo-hydrology

The entire Sundarbans area, comprising of many islands, is deltaic active and hydrologically dynamic. The coastal morphology is further characterized by different features like, vast networks of rivers and channels, heavy water discharge carrying sediment, strong tidal waves, cyclone and surges. The three divisions in Bangladesh are (i) Eastern region, (ii) Central region, and (iii) Western region, and in Indian part it is named as the south-eastern region. The central region runs east from the Tetulia River to the big Feni River estuary, including the mouth of the combined flows of the Ganges-Brahmaputra-Meghna (GBM) Rivers (Akter et al. 2010; Islam et al. 2017). This is the reason that this region is characterized by heavy sediment input, formation of new *chars* (sedimented raised bed), and river bank erosion, and accretion. The western region covers the coastline westward from the Tetulia River to the international boundary located at the Harinbhanga River (Fig. 2.1). This region is mostly covered with dense mangrove forests having a reduced river bank erosion. The rivers of the region are mostly stable; land accretion does not occur massively (Jalal 1988). Figure 2.2 shows the Sundarbans mangrove wetlands and the river system in the mangrove forest areas in both countries. The southeastern part of the Sundarbans in West Bengal (India) starts from Harinbhanga river in the east to Hoogly River in the west. In between, the Gosaba, Matla and Suparnakhali river systems are playing a potential role to protect the coastal landscape and balance the Sundarbans coastal deltaic ecosystem (Fig. 2.2). The central region in Bangladesh has deltaic characteristics. The GBM rivers discharge at the rate of about 1.5 million $m^3\ s^{-1}$ during the peak period (Hasan and Mulamoottil 1994). The fluvial and tidal landscapes and related features are created by four mighty rivers (Ganges – Brahmaputra – Meghna and Hoogly river) in the Ganges coastal deltaic wetlands regions between Bangladesh and India (Islam 2003; Islam and Gnauck 2007a, b). All the

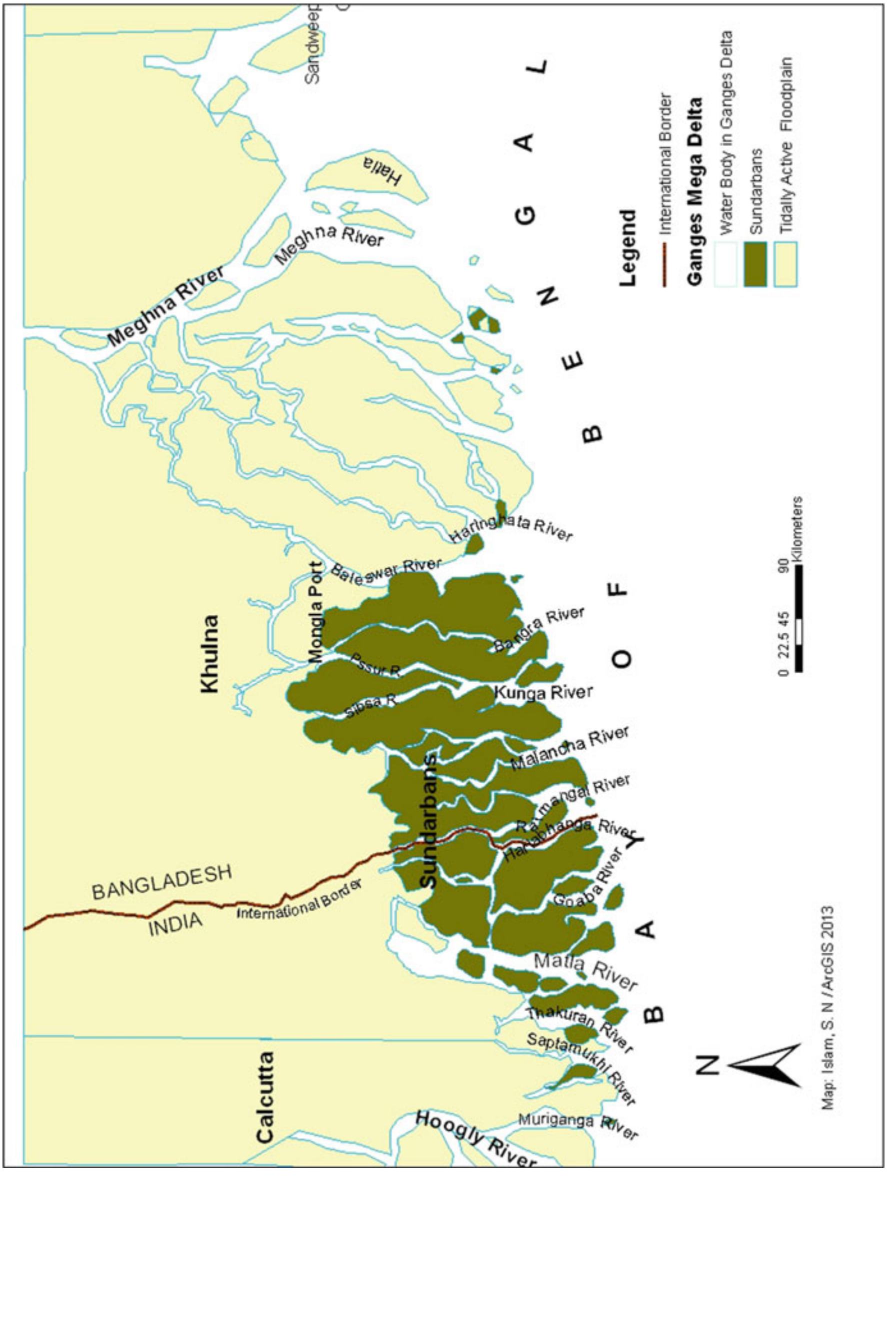

Fig. 2.2 The Sundarbans coastal mangrove delta and river system. (Source: The figure prepared by author through ArcGIS 10.2 in 2013)

rivers have its origin in the Himalayas and carries an estimated annual sediment load of 2.4 billion tons (Elahi et al. 1998) and having a profound effect on the floodplains. Silt deposition in the forest poses a threat to the river flow but supports vigorous growth of mangrove vegetation. The silt deposition causes a rise of the forest floor but due to irregular flow of tidal water, mangrove regeneration does not take place properly. Area is densely populated and plays important economical role – wood production and agricultural cultivation with allied activities.

2.4.2 Groundwater Hydrology and Tidal Features

Ground water issue is a potential factor in hydrology studies where water is a valuable natural resource to man and other living beings (Rahman and Ahsan 2001). Under natural conditions, freshwater flow toward the sea limits the landward encroachment of seawater. The surface water disturbs the dynamic balance between freshwater and seawater, which, in turn, allows seawater to intrude into the usable parts of aquifers (Rahman 1988; Hossain 2001; Iftekhar 2006). Ground and surface water quality is dominated by both natural and anthropogenic influences, where the former is governed by the local climate, geology, etc., and the latter by the construction of dams and embankments, irrigation practices, indiscriminate disposal of industrial effluents, etc. (Rahman and Ahsan 2001).

The amount of the Ganges water flow into Bangladesh is remarkably affected by the amount of water drawn at the Farrakka Barrage in India since 1975. The Ganges flow in 1962 was 3700 $m^3\ s^{-1}$, whereas it was 364 $m^3\ s^{-1}$ in 2006 and 370 $m^3\ s^{-1}$ in 2010 (Goodbred and Kuehl 2000; Islam and Gnauck 2009a). The Ganges water flows is also related to the condition of groundwater hydrology. The river water flows and rainwater on the surface dominate and balance the groundwater condition in the Sundarbans region, and the reduction in flow rate has resulted in increase in high rate of saline seawater intrusion in the upstream areas. Such diversion of upstream waters resulted in falling groundwater tables and greater salinity in downstream for Bangladesh especially in the Sundarbans region. Some portion, almost 16% of the flows of the Gorai River, meets the Haringhata-Baleswar estuary system at Madhumati river and the other 85% flows to join the Passur Basin at Nabaganga River. The last part of the Gorai River joins the sea as Baleswar River (Islam and Gnauck 2008, 2009a, b; Islam et al. 2017).

Water salinity intrusion of the whole Sundarbans region is dependent on hydrological condition and its changing behaviour. Water level inside the Sundarbans is highly fresh and dependent on the upstream river inflows and on the tidal oscillation at the coast (Siddiqi 2001). Tides in the Bay of Bengal are semi-diurnal exhibiting two high water and two low water levels per day. The variations in water level and tidal amplitude experienced at the coast are also propagated inland during each tidal cycle. It has been observed that the tidal range in the northern fringe of the Sundarbans mangrove forest is higher than that in the southern bay. The lowest record of tidal range was 2.74 m and the highest in the east is higher than that in the southern Bay, while the highest range was 5.12 m (Islam and Gnauck 2009a, b; Islam et al. 2017).

The maximum inundation period during the spring tide is around 3–4 h, the average velocity of micro-current varies from 10 to 20 cm s^{-1}. Both siltation and erosion occur at the end of monsoon. The maximum net siltation and erosion at the end of monsoon were found to be around 50 and 19 mm, respectively (Islam et al. 2017). The hydrological changes in the Sundarbans region will pose a new threat for the mangrove ecosystem, its goods and services. There is close correlation with hydrological cycle and the mangrove ecosystem in any region of the mangrove world.

2.4.3 River Hydrology

The Bengal delta is the world's largest delta comprising of 100,000 km^2 of riverine flood plain and deltaic plain (Goodbred and Nicholls 2004). The high tide energy results in tide dominated deltas, like the Meghna estuary, where distributaries with linear river mouth bars are present (Miah 1989). Sediment deposition occurs only by river flushing in the river-dominated delta, while in tide-dominated deltas, sediments are reworked and redeposited (Goodbred and Nicholls 2004). Every year about 1×10^{12} m^3 of freshwater is brought into the Meghna estuary by the three major rivers the Ganges, the Jamuna and the upper Meghna (Nishat 2006). These rivers are major source of water supply to the wetlands and make the balance of wetlands ecosystems. The largest rivers in Asia are created from the Himalayas and Tibetan pleatue (Jalal 1988). As a whole, the Bramaputra (Jamuna) river carries water flowing at the rate of 60,000–100,000 m^3 s^{-1} and about 600 million tons of sediment particles, major part of which are sand and clay in each year (Jalal 1988; FAP 24 1996; Islam and Gnauck 2008, 2009a, b; Islam et al. 2017). The reduction of the Ganges freshwater in the upstream area is the root cause of salinity intrusion in the south-western region which is affecting the Sundarbans coastal mangrove and saline wetlands in both countries in Sundarbans (Nishat 2006).

2.5 Threats to the Ecosystem

2.5.1 Soils: Delineation of Problems and Risk Factors

The reduction of Ganges fresh water in the upstream area is the main reason of salinity intrusion in the south-western part of Bangladesh and some part of south-eastern West Bengal (India). Therefore, the result of increased salinity has damaged vegetation, agricultural cropping systems, and changing the cultural landscapes in the Sundarbans region. The impact of soil starts with the destruction of surface organic matter and of soil fertility for mangrove plants production (Islam and

Gnauck 2007a, 2009a). The changes alter basic soil characteristics related to aerations, temperature, moisture and the organisms that live in the soil. Figure 2.3 demonstrates the soil and water salinity intrusion pattern in the Sundarbans and surrounding areas where soil delineation impacts are very high in agricultural cropping system and drinking water supply and management (Islam and Gnauck 2009a, b).

The core elements of ecosystem such as soil, water, vegetation and wildlife are strongly affected due to fresh water shortage and human influences. Water scarcity of the Ganges flow is challenge for coastal food security and mangrove wetland ecosystem protection, and for further improvement of coastal saline environment. Figures 2.3 and 2.4 are displaying the real scenarios of the Sundarbans mangrove deltaic sensitive ecosystem.

There are many reasons for the mangrove degradation in the Sundarbans Deltaic region. More sensitive and critical issues are human uses of mangroves, fishery development, hyper-salinity, salt pans, salt ponds, and sediment deposition, like sea sand from low lying sand dunes, sea beaches and sand bars, which are transported or drifted into the forest areas by over-wash fan sediment deposition particularly by storms and tidal waves (Wolanski et al. 2009).

2.5.2 Threats to Biodiversity

The delta front sand bodies with different shapes and sizes are unable to hold the surge waters of advancing storm waves that can transport the bulk of sediment from seaward face to inner of the delta plains (Farley et al. 2010). The sediment lobes submerge the forests, wetlands surface, and tidal creeks at a steady rate with increased frequency of storm events in the deltaic coast at present (Wolanski et al. 2009). Mangroves occur in the waterlogged, salty soils of sheltered tropical, and subtropical shores. They are subject to the twice-daily ebb and flow of tides, fortnightly spring, and neap tides, with seasonal weather fluctuations. They stretch from the intertidal zone up to the high-tide mark (GOB 2001; PDO-ICZMP 2005). These forests are comprised of 12 genera comprising of about 60 species of salt tolerant trees. With their distinctive nest of stilt and prop-like roots, mangroves can thrive in areas of soft, waterlogged, and oxygen-poor soil by using aerial and even horizontal roots to gain a foothold (Islam et al. 2017). The roots also absorb oxygen from the air, while the tree leaves can excrete excess salt. Most species typically have relatively widespread distributions, low diversity floras, but overall alpha diversity is very high when terrestrial and aquatic species are considered, very low beta diversity, and low eco-region endemism, while some highly localized species exist with strong zonation along the gradients; showing thereby several distinct mangrove habitat formations. Alterations of hydrography and substrate have considerable impact, although restoration potential is high; mangroves are susceptible to pollution due to particularly oil and other petroleum compounds; and alteration of salinity levels can have dramatic impacts on mangroves. In Sundarbans a

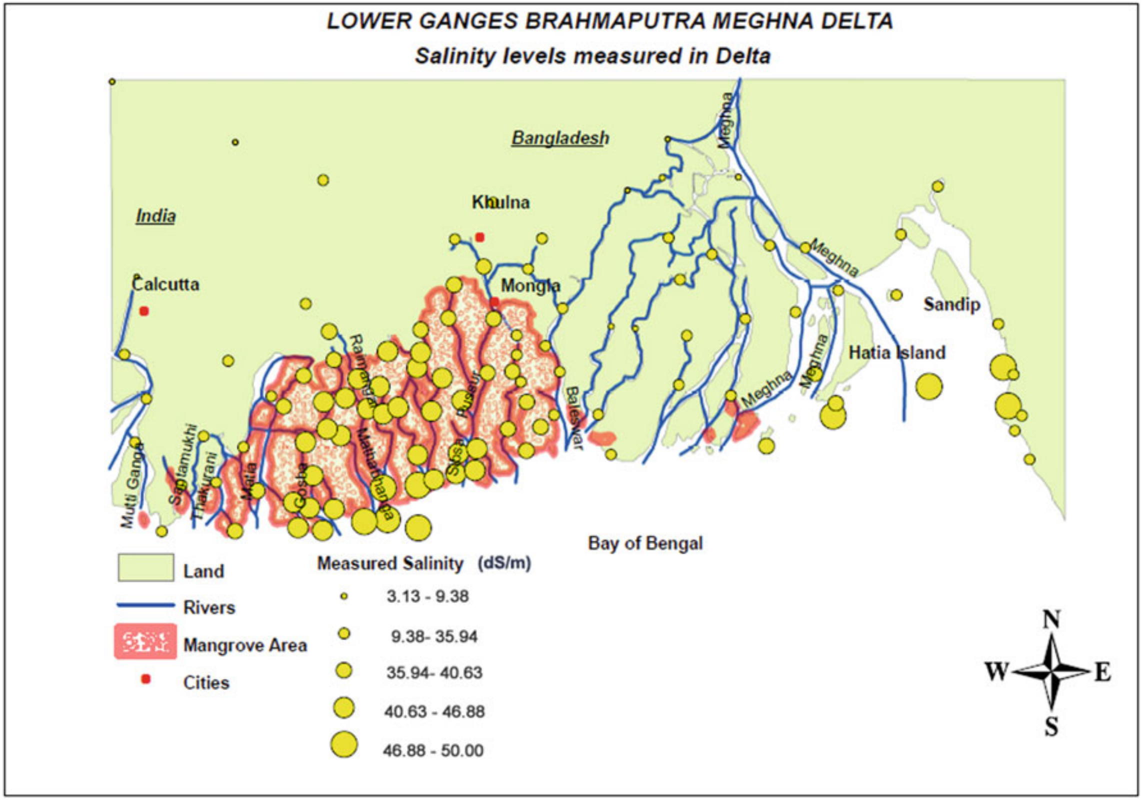

Fig. 2.3 Salinity measured in Sundarbans mangrove and the Ganges-Brahmaputra-Meghna deltaic coastal region in 2015. (Source: Salinity intrusion model was developed by author through ArcGIS 10.2 in 2013)

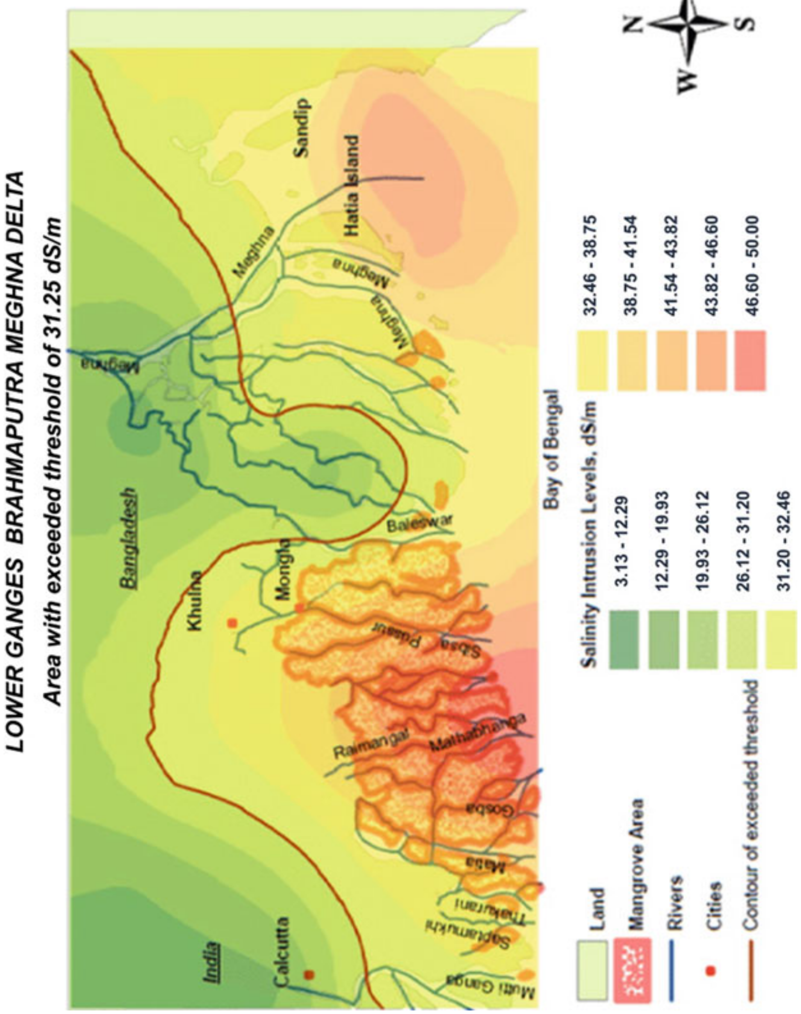

Fig. 2.4 Lower Ganges-Brahmaputra-Meghna-River delta: area which exceeded threatened limit of 31.25 dS m^{-1}. (Source: Salinity intrusion model prepared by author through ArcGIS10.2 in 2013)

large number of mangrove seeds is regularly drifted into the unfavourable sandy substrate after the events of storms, tidal waves, south-west monsoon brace, and HAT (Highest Astronomical Tides) phase currents along the shores of the Bay of Bengal, which is creating another type of threat for mangrove biodiversity (Islam 2016; Islam et al. 2017). The habitats, biotops and ecosystem also serve as habitat for especially four dominant tree species of the Sundarbans. But the existence of these and many more native species is endangered (Islam et al. 2019). So the native species are approximately decreasing significantly by the year 2100 due to sea level rise (88 cm) in the Sundarbans area compared to the year 2001. Species Biswas found 23 invasive which belong to 18 families and 23 genera. These species are highly invasive, six species are moderately invasive and the remaining are potentialy invasive (Biswas et al. 2007; Islam et al. 2019).

2.5.3 Global Warming and Future Projection

Climate change and sea level rise, induced by global warming, also influence the ecological stability of the coastal zone; and the situation becomes serious when the climate change phenomenon is compounded with various natural and anthropogenic factors, and, as a result, the natural resource base of the zone is on a declining trend. This affects the productivity of agricultural and allied fields including fishery. Failing ecosystem productivity further degrades the coastal deltaic ecology, and quality of life of the local communities (Dasgupta 2001). As a result of global warming, relative Sea-Level Rise (SLR) movement has an immediate and direct effect on the coastal inter-tidal ecosystems, particularly on vegetation. A rise of relative SLR decreases the influences of terrestrial processes and increases the influence of coastal marine processes (Islam 2001). The world's great deltas are the most densely populated, and most vulnerable of coastal areas are threatened by sea level rise (Broadus 1993). Global warming, sea level rise, and vulnerability of coastal wetland ecosystems are factors that have to be considered to draw long-term management strategy for dealing with the coastal mangrove wetland issue (Fedra and Feoli 1999). The impacts of climate change in any given region depend on the specific climatic changes that occur in that region. Local changes can differ substantially from the globally averaged climate change (Harvey 2000). In Bangladesh it has been projected by IPCC (2007) that 3 mm per year sea level rise may occur before 2030 and might cause 2500 km^2 land (2%) to be inundated. About 20% of the net cultivable area of Bangladesh is located in the coastal and offshore island (Fig. 2.5), which is under threat due to the above-mentioned causes.

A very recent study on the Ganges deltaic coastal area in Bangladesh by IPCC report shows that the mean tidal level at Hiron Point is showing an increase of 4.0 mm per year which is higher than the global rate. Soils in this area are affected by different degrees of salinity (Rahman 1988; IPCC 2007). About 203,000 hectare very slightly, 492,000 hectare slightly, 461,000 hectare moderately, and 490,200 hectare strongly salt affected soils are assessed in south-western part of the coastal area (Fig. 2.5). The climate change impact issue is a new threat for the coastal area of Bangladesh. In Sundarbans, sea level rise would further result in saline water moving into the delta which would be the major threat for mangrove and coastal wetland ecosystems (IECO 1980). It was projected in respect of different SLR that for 10 cm rise 15% of the land in Sundarbans will be inundated and will affect 17% of the population rendering them homeless. A detailed account of climate change and probability of inundation of land has been projected in a separate chapter by Danda and Rahman in this book.

The Fig. 2.5 shows that 3 m SLR would cause much worse scenario for Bangladesh when almost one-third of land could be inundated by saline water. The reduction rate of mangrove areas will be from 50% to 75% and would be more harmful for coastal ecosystems in the estuaries (IPCC 2007). Besides, other environmental problems will arise in the coastal belt such as, water pollution and scarcity, soil degradation, deforestation, solid and hazardous wastes, loss of bio-diversity, estuary landscape damage, and river bank erosion, all of which will create a lot of new challenging problems for human livelihood in the coastal region.

2.6 E-flow of the Catchment River Network Including its Water Quality

The flows of the world rivers are increasingly being modified through impoundments in dams and weirs, besides abstractions for agriculture and urban water supply, drainage return flows, maintenance of flows for navigation, and structures for flood control (MEA 2003). These interventions have caused significant alteration of flow regimes mainly by reducing the total flow and affecting the variability and seasonality of flows. It has been estimated that more than 60% of the world rivers are fragmented by hydrological alterations. This has led to widespread degradation of aquatic ecosystems by MEA or Millennium Ecosystem Assessment (2003). Available literatures have been reviewed for searching out available techniques for assessing e-flow requirements. In the previous studies, the key information and recommendations of different techniques under different environmental values were described with their limitations, advantages and cost effectiveness. These have been applied for e-flow assessment (EFA) in different river systems in Bangladesh. This study assists to propose a best practice framework for the application of techniques to EFA (Akter et al. 2010).

Akter (2010) stated based on the reports of Tharme (2000, 2003) that “there is no specific guideline for assessing e-flow. However, several methods, approaches and frameworks are being applied in different countries including Australia, South Africa (SA), United Kingdom (UK) and United States of America (USA) depending on their river function. Mainly it depends on stakeholders’ decision on the desired character and health condition of a certain ecosystem”. In the most recent review of international e-flows assessments, Akter (2010) recorded 207 different EFA methodologies applied over 44 countries (Tharme 2000, 2003). Several

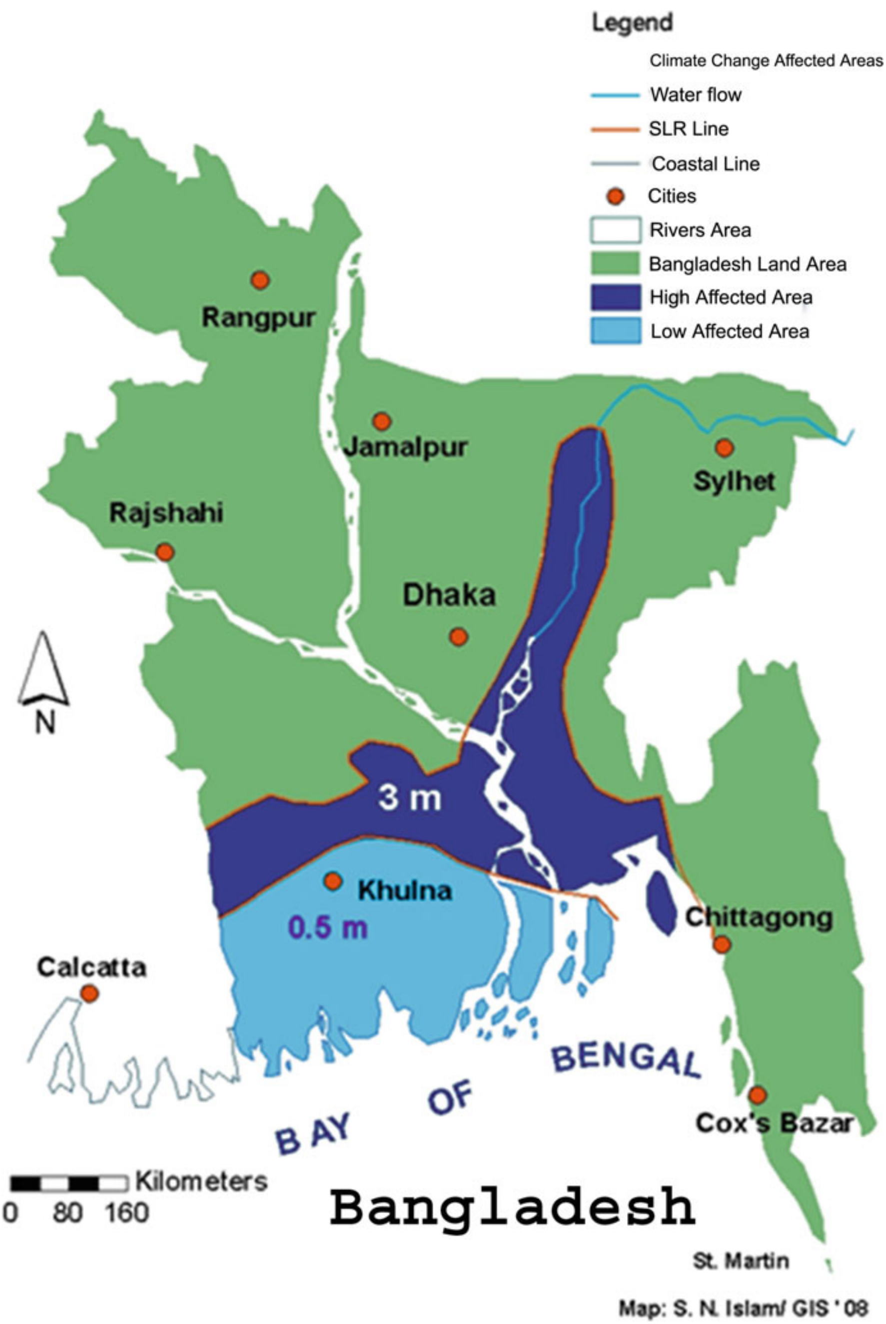

Fig. 2.5 Climate change impacts in the coastal region of Bengal Delta and Sundarbans region. (Source: Akter et al. 2010, open access)

categorizations of these methodologies exist. Many EFA methods have been applied in Australia and modified according to circumstances. Reviews can be found in 2009 (Tharme 2000, 2003; Akter 2010). Above researchers have set out these methods under the headings of geomorphology and channel morphology, wetland and riparian vegetation, aquatic invertebrates, freshwater and estuarine fish, water dependent wildlife, and water quality (Tharme 2000, 2003; Akter 2010).

2.6.1 Methodologies of Measurement of E-flow in Various Countries

Developments in EFAs in South Africa have advanced dramatically during the past decade (Akter 2010). Akter (2010) presented an overview of the historical and local evolution of e-flow methodologies. Methodologies are considered the most appropriate for South African conditions, where there are some constraints. Those constraints are historical, hydrological, ecological with 11 geomorphological data on the river systems of concern; limited finances; extreme time pressures with future water-resource development projects; and limited manpower and expertise. Akter (2010) stated, based on Tharme (1997), that a multi-scale approach to EFAs for South Africa, comprising of a three-tier hierarchy of methodologies with professional judgment, is exercised at all levels. Akter (2010) recommends further advancement of the Building Block Method (BBM) for its most effective use at this level, for instance, by incorporating ecologically relevant hydrological indices into the hydrological component and by biotope-level modeling. It is noteworthy that Downstream Response to Imposed Flow Transformations, DRIFT, developed subsequently, incorporates early elements of both these features (Tharme 2000, 2003). With rivers of high conservation priority, it would be appropriate to apply elements of a suitable, internationally recognized habitat simulation methodology within or in conjunction with a holistic methodology, like the BBM or DRIFT, where the flow requirements of key, ecologically important or rare species need to be addressed (Tharme 2000, 2003; Akter 2010). This would represent the final, most resource-intensive level of the proposed hierarchy. Considerable effort would need to be expended, however, in order to select the most appropriate techniques from the wide range available, and to train and guide researchers in the development and application of these techniques in a local context (Tharme 2000, 2003; Akter 2010).

Before Farakka Barrage construction (1934–1975), the mean of yearly maximum, minimum and mean flow were calculated as 73,000 m^3 s^{-1}, 1190 m^3 s^{-1} and 11,692 m^3 s^{-1}, respectively; whereas, after Farakka Barrage construction (1976–2005), those values were calculated as 77,438 m^3 s^{-1}, 261 m^3 s^{-1} and 11,195 m^3 s^{-1}, respectively (Chowdhury and Haque 1990). The detail impact analyses are discussed and given in Table 2.1.

The relative elevation of the coastal south-west region of Bangladesh and south-east region of West Bengal of India have been widely reported by different studies to assess the required E-flow in the regions and the same was validated through direct

Table 2.1 Percentage of mean annual flow (MAF) in Ganges River (Akter 2010, p. 89, open access)

Percentage of MAF m^3/s	Pre-Farakka (1934–1975)	Post-Farakka (1976–2005)
200% (flushing flow)	23,029	22,715
60–100% (optimum range)	6909–11,514	6815
60% (outstanding)	6909	6815
50% (excellent)	5757	5679
40% (good)	4606	4543
30% (fair and degrading)	3454	3407
10% (poor)	1151	1136

measurements (Akter 2010). On 25 May 2009, Cyclone *Aila* struck West Bengal in India and south-west region of Bangladesh as a relatively weak category 1 storm, causing embankment failures, tidal flooding and the displacement of over 100,000 inhabitants of the coastal regions, like Koyra, Shyamnagar and Dacope in Khulna region (Akter 2010). A detailed account of the nature and extent of damage has been presented by Paul and Chatterjee in a separate chapter in this book. At the Polder 32 in Dacope in Khulna, *Aila* cyclone caused five major breaches of the embankments that protected the island's western margin despite a storm-surge height just 0.5 above the spring high-tide level (Akter 2010). The exact mechanism of failure at these locations remained unknown, while the other four of the five failures occurred at the mouths of former tidal channels blocked by the embankments. All breach sites had experienced ~50–200 m of river bank erosion in the decade before the storm. In contrast, the adjacent Sundarbans, ~100 cm higher, was inundated only during spring high tides (~37% of all tides) to a mean depth of just 20 cm for 1.7 h day^{-1} (Akter 2010). The high rates of sedimentation following embankment breaches exemplify the efficiency with which the Ganges–Brahmaputra fluvio-tidal system can disperse sediment to areas of accommodation, particularly where land has been starved of sediment for extended periods of time (Islam 2007a). To understand the origin of elevation offset between the polder landscape and Sundarbans, it may be necessary to establish an account to work out for differences among local, relative water levels, and the natural and human-altered landscapes (Turner et al. 2001; Tress et al. 2005).

2.7 Government Policies to Upswing the E-flow and Projected Impacts on Soil Properties, Crops Growth, Fisheries, Forestry and Biodiversity

The salinity trends are higher in the Sathkhira, Khulna, Bagerhat, Borguna, Jhalokhati, Potuakhali, Bhola and southern part of Noakhali districts in Bangladesh. The trends are higher in the south-western region of Bangladesh and comparatively less saline intrusion occurred in the eastern region of the coastal region. These trends are also affecting the whole coastal urban ecosystems (Islam 2001, 2006; Akter et al. 2010). The available drinking water and its quality are not enough to meet the demand of the urban citizens. The surface and groundwater in the coastal region is affected by high saline water intrusion. This is deteriorating the quality of drinking water (Adel 2001). Due to the penetration of saline water the soil is also becoming highly saline and soil fertility is getting low. Therefore, the urban flora and fauna are also facing trouble to receive quality water for vegetation growth and survival of fauna in the urban areas (Chowdhury and Haque 1990).

2.7.1 *Water and Soil Salinity in the Wetlands*

The wetland areas in the coastal region of Bangladesh are affected due to high rate of water and soil salinity intrusion. In general, the annual pattern of salinity changes in the Sundarbans region is also related with the changes of freshwater flow from upstream rivers. The adverse effects of increased salinity on the ecosystem of the Sundarbans mangrove wetlands are manifested in the drying of tops of Sundari (*Heritiera fomes*) trees, retrogression of forest types, slow forest growth, and reduced productivity of forest sites (DoF 2003). The peak soil salinity level was found to be about 40.63 dS m^{-1} in 2001 and 2002, and minimum soil salinity was found to be about 7.81 dS m^{-1} during the post-monsoon period of the same years, when huge fresh water supply was available, which mean that fresh water flush out high amount of salts in soil (IWM 2003). The salinity levels crossed the salinity threshold value for the mangrove wetlands ecosystems in the coastal region. Some mangrove species have dried and displaced due to high salinity penetration and intrusion into the coastal area in Bangladesh.

The soil salinity in the southern part of the Sundarbans mangrove forest remains less than 7.81 dSm^{-1} during monsoon and starts to increase at a steady rate to 23.44 dS m^{-1} during the dry season (IWM 2003). Salinity in the western part in not reduced to low salinity range even during monsoon period; salinity increases at a steady rate during the dry periods. Almost 265 km^2 area under *Heritiera fomes* type of forest is affected moderately and 210 km^2 area was severely affected, which is one of the main threats for a sustainable mangrove forest management and its ecosystems (Islam and Gnauck 2008, 2009a, b).

The highest soil salinity levels measured were ECs 41.2 dS m^{-1} at Nilkamal, ECs 40 dS m^{-1} at Mirgang, and ECs 24 dS m^{-1} at Munchiganj point in the north-western Sundarbans mangrove coastal wetlands region. The increasing salinity levels are major threats for both biotic and abiotic factors of mangrove wetland ecosystems in the region (Islam and Gnauck 2009b).

The severity of salinity problem in the coastal wetlands increases with the desiccation of the soil (Fig. 2.6).

The coastal region covers an area about 29,000 km^2 or about 20% of Bangladesh. The coastal areas of the country cover more than 30% of the cultivable lands of the country (Jabbar 1979). About 53% of the coastal areas are affected by salinity. Salinity causes unfavorable environment and hydrological situation that restrict the normal crop production throughout the year (Iftekhar 2006). Soil salinity, besides on the soil surface, is a major concern for surface water in many coastal urban towns

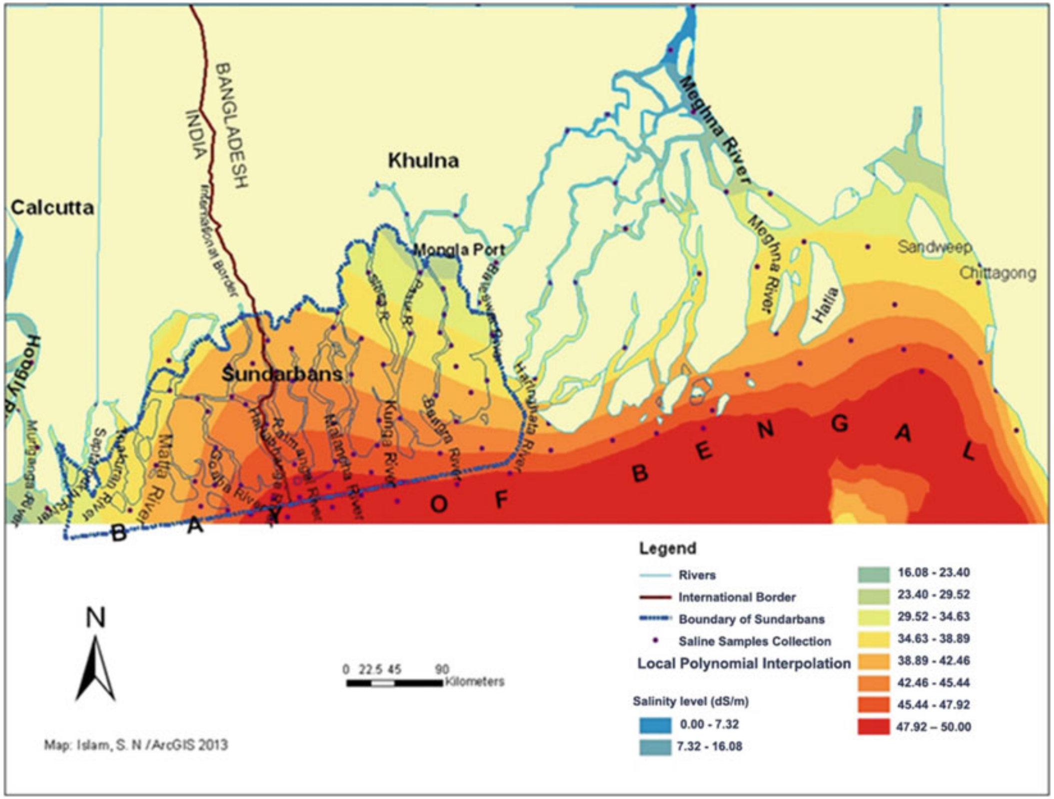

Fig. 2.6 Salinity intrusion pattern in the Sundarbans mangrove deltaic region of Bengal coast. (Source: Salinity model figure was prepared by author through ArcGIS 10.2 in 2013)

(Mohiuddin 2005). Based on a study of ESCAP (Economic and Social Council for Asia and the Pacific) GOB (Government of Bangladesh) has referred six sets of constraints for the development of a strategy for the coastal resource management in Bangladesh (ESCAP 1988).

Policy making includes planning for coastal resources, integrated resource management, coastal wetlands and marine resources sustainability, local environmental ecological perspective, and knowledge on coastal environment and its understanding (Jalal 1988; Akter et al. 2010). The National Water Policy, 1999 (GOB 1999, 2001) of Bangladesh also gives due importance on research and development of knowledge and capacity building for sustainable management. In article 3 of the NWPo, the objective was to develop a state of knowledge and capability that will enable the country to design water resources management plans by itself with economic efficiency, gender equity, social justice and environmental awareness (GOB 1999). In the article 4.15, (GOB 1999) the following specific objectives were not ensured, such as:

- Develop appropriate technologies
- Arrange awareness training and capacity building
- Develop and promote water management, and
- Educate skilled professionals for water resource management

The National Water Policy of Bangladesh provides a guideline framework for the nation. The quality of coastal water resources is dependent on the supply of upstream fresh water supply and its availability in the coastal region (Miah 1989). Sea level rise and tidal inundation factors are also potential issues, therefore some coastal issues such as coastal urban drinking water issue should be incorporated in the NWPo in Bangladesh (Akter et al. 2010).

2.7.2 Degradation of Mangrove Ecosystem and Biodiversity

The salinity investigation results show that the south-west Bengal coastal regions and, within this area, the Sundarbans Natural World Heritage site, is carrying the highest rate of water salinity rise, which is unbalancing the coastal ecosystem and general ecology (Jagtap 1985). According to salinity approximation, this high rate of rise is harmful to rural and urban biodiversity as well as to the urban drinking water (Brown 1997; Islam et al. 2017). The Fig. 2.3 demonstrates the water salinity intrusion trends in the south and south-west region of the Ganges deltaic region, which includes the entire Sundarbans mangroves.

Four major cities and 136 small towns are located in the coastal region, and a major portion of the inhabitants are dependent on mangrove resources in the coastal region. Most of the towns are affected through salinity intrusion and sea level rise impacts in the region as Sundarbans mangroves are also affected due to high salinity intrusion. Therefore, the investigation results of salinity modelling in the South and South-west coastal deltaic regions, including the coastal rural and urban ecosystem goods and services, are under threat and the biodiversity is getting reduced (Costanza 1997; Deb 1997).

Especially, the coastal mangrove and agro-biodiversity loss is a common scenario in the Ganges-Brahmaputra-Meghna Rivers deltaic region between Bangladesh and India (Anwar 1988). The Fig. 2.2 demonstrates the scenarios of the coastal mangrove forest and wetland region in the Sundarbans and its Sundarbans Natural World Heritage Site in Bangladesh. The quality of mangrove forest as well as wetland water and soil are rapidly degrading due to high saline water intrusion and anthropogenic influences (Anwar 1988; Miah 2001; MOWR 2005).

The study also found that the mangrove reduction rate is about 45% in both countries (Bangladesh – India). Deforestation is rising, and land cover is changing due to shrimp farming, salt farming, agricultural land extension, and urbanization extension and settlement development. These development processes adversely affect coastal fish production and lead to a loss of agro-biodiversity and coastal floodplain biodiversity, and of livelihood, which mean to negatively influence 3.5 million people, who are dependent on natural resources in the coastal region in Bangladesh (Anon 1995; Primavera 1997; Wolanski et al. 2009). Almost the entire mangrove forest needs freshwater supply from the upstream. In the Sundarbans Ganges deltaic coastal region, the two potential rivers, such as the Passur-Mongla and Chunar-Munchigannj cause high rate of salinity intrusion. The Fig. 2.3 shows the high salinity intrusion trends in the coastal mangrove forest and wetland region. The salinity model also demonstrates that the salinity trends are much higher in the south-western region of the Sundarbans mangrove wetlands regions (Anwar 1988). The salinity was 30.37 dS m^{-1} in 2003, whereas in 2010 the salinity was 38.32 dS m^{-1} in the Passur-Mongla river point (Joseph 2006).

The salinity penetration in the upstream areas of the coastal zone is one of the main obstacles to maintenance of water quality for drinking, irrigation and fisheries purposes (Grigg 1996; Islam and Gnauck 2009b) as well as for the mangrove ecosystem and biodiversity, in general. Already the coastal mangrove and wetland ecosystems have been recognized as a driving force for biodiversity conservation and coastal urban socio-economic improvement (Nishat 2003; Ahmed and Falk 2008; Islam et al. 2017).

Also, in the Ganges-Brahmaputra rivers deltaic floodplain alone approximately 2.1 million ha of wetlands have been lost due to flood control, drainage, and irrigation development (Khan et al. 1994; Goodbred and Nicholls 2004). Therefore, coastal urban wetlands biodiversity is facing serious challenges from salinity intrusion, environmental changes and anthropogenic impacts (Sarker 1993; Sarker et al. 2003; Nair 2004; Ahmed and Falk 2008; Goodbred and Nicholls 2004).

2.7.3 Degraded Mangrove Ecosystem and Threatened Community Livelihoods

The benefits of mangrove forests serve as diverse habitat for many species, including fish, birds, reptiles, amphibians, mollusks, crustaceans and many other invertebrates (McGarigal and McComb 1999). Mangroves produce little leaf and detritus matter; and the leaves of the mangrove trees are valuable sources of food for animals in coastal waters (Helmer and Hespanhol 1997).

Mangrove is a rich source responsible to create fish diversity and satisfy the local demand. Fishing is a very important issue and activity in the Sundarbans (DoF 2003). The fish production has been reduced since the land use and landscape have been changed, which is not suitable for fish cultivation (Freemark et al. 1996; Daily 1997). At present the area is providing only shrimp and some marine fish species in the offshore area. Up to 80% of global fish catches are directly or indirectly dependent on mangrove wetlands (Fujimoto 2000). The Sundarbans mangrove forest produced an average of 600 tons of nutrients per hectare to provide a great source of natural food in the coastal offshore area (FAP 1996). It is a good service and poles for fish traps. Fish, crustaceans and mollusks can be harvested from mangroves. Aquaculture and commercial fishing also depend on mangroves for juvenile and mature fish species.

Clearance of mangroves in the south-east causes a loss of coastal habitat, aquatic resources, increased erosion, and vulnerability to natural disasters (Nishat 1988). The coastal communities are coping with the threats under reduced resources. The livelihood assets, such as physical asset, financial asset, human asset, natural asset, economic asset, social asset, and cultural and heritage assets were interconnected for maintenance of local coastal community livelihoods (Hossain and Lin 2002; MEA 2003). In general, mangrove vegetation acts as a barrier against damage due to natural disaster. Coastal water resources have been supporting the livelihoods of the poorer sections of society. In one instance, the Gorai River which was used to play a potential role, by enormous opportunities for varies fisheries, aquatic resources, river navigation, and mangrove forest goods and services (Miah 1989; EGIS 1997, 2000), is now fully dead because of anthropogenic activities (Hidayati 2000; Miah et al. 2010). The salinity problem in soil, aggravated by the brackish water shrimp farming introduced, increases beyond tolerable limits for agricultural crops and other vegetation (Adeel and Pomeray 2002; FAO 2007; Miah et al. 2010), thus affecting the livelihood. The river water salinity shows that the upper limit (30–45 dS m^{-1} during the peak period) is beyond the tolerable limits for crops and vegetation (Hossain and Lin 2002; Miah and Bari 2002; Miah et al. 2010).

The most alarming threat to the Sundarbans is destruction of fauna and flora, because 50,000 fisherman and local coastal communities are directly dependent on the mangrove coastal natural resources. Encroachment into the mangrove forest created multifarious impacts on both resources and livelihoods of the local inhabitants. Diverse livelihood activities of the local inhabitants in its vicinity were nearly lost. Attempt is made on building of the remaining reserved forest resources (Miah et al. 2010).

There are not enough initiatives or policies to protect mangrove ecosystems in the south-east coast of Bangladesh. The unplanned policy has created crucial problems on coastal ecosystems and threat for community livelihoods (Peine 1998; Richards and Flint 1991). Especially the coastal indigenous people, who were totally dependent on mangrove resources, are facing critical problem for their livelihoods from natural hazards and cyclones. In Mexico, Nicaragua, Ecuador and Panama the indigenous people in the coastal regions are asking for the protection of mangroves. The demand of mangrove protection is getting popular in India, Sri Lanka, and other parts in Asia Pacific zone too (UNEP 1995). There is an example that the Government of India and Ecuador has banned the further cutting of mangroves for shrimp farms, but in Ecuador, 127.5 $km^2$of mangroves were still illegally cut even after the ban. This type of illegal activities is continuing in many countries, even in Bangladesh. Therefore, a common universal policy and guideline framework is necessary to protect the mangrove forests which will secure the livelihoods of the coastal community (Gopal and Chauhan 2006; Wolanski et al. 2009). Since 1996 afforestation programme is supported by the World Bank and Government of Bangladesh. Several projects: Forest Resources Management Project (FRMP), Sundarbans Biodiversity Conservation Project (SBCP), etc. are in progress. The floral richness is one of the highest in the world mangroves and consists of no less than 123 woody plant species (Dutta and Iftekhar 2004; Gopal and Chauhan 2006). However, in spite of many programmes currently in progress to protect the mangrove ecosystem and the rich biodiversity in Sundarbans across both countries it does not appear to be adequate either to conserve the ecosystem, at the same time, maintain the livelihood of the coastal community.

2.8 Conclusions

Factors damaging the ecology including the rich biodiversity of Sundarbans across both countries, as well as, limitations in the various approaches currently underway for arresting the damage and maintain the livelihood of the coastal community have been discussed. It is amply clear that the issues and problems being trans-boundary in nature are complimentary to each other. What's more, the climate change phenomenon, which is one of the hardest issues to be solved, making the sub-continent increasingly disaster-prone, and complicated over time, is looming large over the entire eco-region. Therefore, what probably is lacking is a holistic and integrated approach covering both countries, wherever possible and necessary, since no individual effort will result in a lasting solution. Following are the immediate suggestions of general nature.

- Mangrove wetland ecosystems have historically been considered as wastelands unworthy of consideration for conservation. As a result, wetlands have frequently been altered or lost because of their ecological functions and values to society not having been understood. Therefore, it should be introduced to the people as a common property in view of its importance and community rights (Rahman and Haque 2003; Rahman 1995; Islam 2007b).
- Based on the present degraded environmental condition, the coastal zoning approach should be included and that could improve land use planning, minimize conflicts over land tenure, and identify appropriate areas for shrimp cultivation, without destruction of mangrove wetlands and the ecology, and those areas need to be protected. There is also need to improve information system to manage and plan for future growth.
- Improvement of the existing mangrove wetland resource related policies, strategies and common conflicts in the areas, where rural communities are dependent on the mangrove ecosystems services, should be understood.
- Capacity building of environmental awareness and development of institutional organizations at international level with legislation rights to regulate all activities should be planned.
- Ensure with short- and long-term strategies planned at the trans-boundary scale for the Sundarbans wetlands eco-region to meet food security for improved livelihood of the coastal community for both countries, and without damage to the ecological balance, in the Ganges-Brahmaputra deltaic landscapes in Bangladesh and West Bengal of India.
- Both countries should show strong political commitments and wills for better management and conservation of the mangrove forest wetlands. An integrated wetland ecosystem management plan and policy guidelines should be developed, based on the findings of several studies, and plan for future studies, if necessary, to address more areas of genuine importance.

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