# Vulnerability of Mangrove Forests and Wetland Ecosystems in the Sundarbans Natural World Heritage Site (Bangladesh)

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**Abstract**

The Sundarbans Natural World Heritage Site is lying within the Bangladesh coastal region, which is gifted with vast natural resources, a delta, tidal flat, mangrove forests, marches, lagoons, bars, spilt, estuaries and coastal ecological environment. These habitats, biotopes and ecosystems also serve as potential resources for anthropogenic communities: 36.8 million people are living within the coastal region of Bangladesh and being dependent on coastal water resources, for which the Sundarbans Natural World Heritage Site is giving some protective management support. Nevertheless the natural coastal resources are drastically reducing due to unplanned use by the community and the stakeholders, although the Ganges-Brahmaputra-Meghna Rivers are carrying 6 million $m^3/s$ water. As a result, the Sundarbans mangrove forests and wetlands are vastly affected through these developments. The present situation demands that an integrated natural resource management plan is necessary for the protection of the mangrove coastal ecosystem. This chapter was prepared based on primary and secondary data sources, as the objectives were to analyze the present coastal mangrove natural resources management status. The study investigates the deltaic Sundarbans natural world heritage site with its mangrove forests and wetlands ecosystem development and management strategies to ensure less vulnerability and a sustainable development of coastal mangrove resources in the Ganges-Brahmaputra Rivers deltaic coastal floodplain region of Bangladesh.

**Keywords**

Coastal wetland · Ecosystem · Ganges-Brahmaputra delta · Degradation and management

## 11.1 Introduction

Bangladesh is a land of water, but water is also one the most critical and major problem in the country. The deltaic coastal areas of Bangladesh are especially impacted and more vulnerable. The deltaic coastal areas are about 710 km in length with extending along the Bay of Bengal from the mouth of Teknaf River in the south East to the Mouth of Raimangal River in the south west and including the greater districts of Chittagong, Noakhali, Barisal, Patuakhali and Khulna (Nishat 1988). The coastal region is composed of the land and the sea including estuaries and islands adjacent to the land water interface of south east Bangladesh and the coast can be divided into three distinct regions (Pramanik 1983). Most parts of the Bengal deltaic coastal areas of Bangladesh are an active or nascent delta with vigorous dynamism and the islands or chars are formed, eroded and reformed (Islam 2016). The on the outskirts of the coastal area located Swatch-of-No-Ground submarine canyon (SoNG)[1] being situated on the south of Ganges-Brahmaputra delta near to Dubla Char, is also a major feature only 24 km far from the coast water and from the Sundarbans mangrove forest (Rahman 1988, 2003) being interesting for understanding the geomorphological facts within the entire region.

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[1] The first marine protected area is placed over here at SoNG in Bangladesh, which is also called Ganga Trough.



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Focusing on the Sundarbans Natural World Heritage Site and its mangrove forests and wetlands, the major water challenges will be described in its vulnerabilities in exemplary form. The connection to existing ecosystem services will help in understanding the topical specifications of vulnerability and its focal areas for Sundarbans mangroves. The Sundarbans Natural World Heritage Site is lying in the coastal region of the Ganges-Brahmaputra Rivers Delta, which is the largest floodplain wetland region worldwide and is located in the South Asian Region (comp. Morgen and Mclntire 1959; Khandoker 1987; Sarker et al. 2003; Goodbred and Nicholls 2004; Islam 2016).

With naming some of the water challenges, in the first row the scarcity of upstream fresh water has created serious environmental problems in the coastal region of Bangladesh. This strongly needed upstream fresh water supply to the coastal region is playing a potential role to make a balance within the complex interplay of varied existing ecosystems. Also the oceanic saltwater and tidal pressures or storm winds are giving challenges to the coastal area. In this constellation the coastal mangrove forests and wetlands provide numerous important ecological services to humanity: the tropical and sub-tropical coastal mangrove wetlands provide important ecosystem services to the population living in the hinterland such as by sheltering it from storm winds, capturing salt spray and improving crop production in arid coastal areas (Wolanski 2007). Also the fact of proceeding higher flora and fauna species appearance in variety and population density is giving another multiplicating factor and ecosystem service for mangrove forests and wetlands: it is at the coast where the heavily sediment-laden river water with very little salinity meets the saline sea water. This mixing creates unique ecosystems with unique flora and fauna species appearance that exhibit their presence here in unique habitat forms such as these mangroves and enhance biodiversity. Amongst these mangroves the most important once are the here to be described Sundarbans with its unique tropical mangrove forest and the wild life, the fisheries dominated by economically important species such as Hilsa and Prawns (Rahman 1988, 2003). Mangrove forests and wetlands also safeguard the coast against erosion and guard against loss of capital infrastructure and human lives (Wolanski et al. 2009).

Coastal wetland environment and ecosystem services play also a very important role in the socio-economic development of the Bengal Deltaic coastal region of Bangladesh (Islam 2016). About 25% (35 million people) of population live in the deltaic coastal areas and most families are dependent on coastal natural resources for their livelihood (Hidayati 2000). So a coastal ecosystem such as a mangrove forest or wetland also supply these socioeconomic benefitting ecosystem services for the human population with including building material, fisheries, forage, fuel, timber, and the protection of commercial, recreational, and naval vessels (Williams 1919; Wolanski et al. 2009). Coastal wetland environment and ecosystem services play a very important role in socio-economic development of the Bengal Deltaic coastal region of Bangladesh (Islam 2016) and emphasize the tremendous importance of the established Sundarbans Natural World Heritage Site in a part of this coastal region as balancing spatial area. About 25% (35 million people) of population live in the deltaic coastal areas and most families are dependent on coastal natural resources for their livelihood (Hidayati 2000).

For creating a balance in the variety of existing ecosystems and creating a less vulnerable basis therefore sustainable deltaic coastal wetland ecosystem management is essential for the coastal community's livelihoods as well as other stakeholder's benefits in Bangladesh (Pramanik 1983; Rahman 1988; Costanza 1992; Islam 2007, Islam 2016, Islam and Gnauck 2009a) and especially within the multivariate existing ecosystem services within Sundarbans mangrove forests and wetlands and the protected area of Sundarbans Natural World Heritage Site.

With summarizing the overall research emphasize, the question for sustainable development is a key concept in strongest driving force of the water sector (comp. Grigg 1996; Gleick 1998; Costanza 1992; Islam 2007) and its specific problems and vulnerabilities in Bangladesh and especially in the Sundarbans Natural World Heritage Site. The viewpoint of peaks of vulnerability causes, pressures, states, impacts for mangrove forests and wetlands should guide into possible to be found solutions in decision-making for the specific and unique Sundarbans Natural World Heritage Site.

## 11.2 The Aims and Objectives of the Study

The aims of this study are to understand about unique characteristics and its vulnerabilities of the coastal deltaic mangrove forest and wetland region of the Sundarbans Natural World Heritage Site in Bangladesh. Special emphasize was placed on the interrelationship of the – through mangrove forests and wetlands origins – ecosystem services, its potentiality of coastal socio-economy and community development combined to vulnerability factors and the role for protecting Sundarbans coastal mangrove forest and wetland ecosystem.

There are some specific objectives of this study, which have been recognized such as following:

(i) To understand the characteristics and its vulnerability of the Sundarbans Natural World Heritage Site combined to its catchment area of Ganges-Brahmaputra Rivers and their deltaic coastal mangrove forest and wetland ecosystems as well as its role for the coastal region.

(ii) To investigate in the analysis of the vulnerable (with especially the example of water salinity intrusion) and degraded mangrove forest and wetland ecosystem in the deltaic floodplain regions in Bangladesh.
(iii) The study seeks the adequate coastal mangrove forest and wetlands ecosystem management strategies and
(iv) Making recommendations for future development policies for the coastal natural resources, protection and management of coastal deltaic mangrove degraded ecosystem in the Bangladesh coastal region.

## 11.3 Data and Methodology

The present study was carried out based on primary and secondary data sources. The primary data collected from field investigation in 2003 and 2008. PRA practices were arranged with the local people at Munchiganj near Sundarbans, Koira Upazila, and Mongla port area. The information were collected from Galachipa and Kalapara upazilas of Patuakhali district. Besides these, various reports and published articles in journals and conference proceedings have been used for this study. Published materials, reports and journals were collected from different governmental and non-governmental organizations in Bangladesh. For secondary data collection, CARDMA reports on coastal resource development and management were used very openly. The especial research reports of CARDMA, FAP 24 report, BWDB, CEGIS reports and BCAS reports were also used for this study. Beside these some interviews were arranged with water engineers, environmentalists, geographers, geologists and sociologists and expert people on river systems and its ecology. Besides, the secondary data were collected from the relevant published research works[2] in the country of Bangladesh as well as outside of the country. The collected data were processed, analyzed, and visualized through MS Excel interpolation, VISIO 32, ArcGIS 9.3 and 10.1 software. They were used for vulnerability approximation to investigate in the degraded deltaic coastal floodplain mangrove forest and wetland ecosystems in the Ganges-Brahmaputra Rivers Deltaic region in Bangladesh.

## 11.4 Geographical Location and Physical Characteristics of the Coastal Mangroves in Sundarbans Region

The Sundarbans Natural World Heritage Site and the nearly entire spatial extent of the country of Bangladesh is situated in the Ganges-Brahmaputra-Meghna Rivers catchments and the Bengal coastal zone, for which in the following the geomorphological development as well as its present catchment characteristics should be described in more detail in order to estimate the vulnerability factors in a more precise way (Goodbred and Kuehl 2000, Islam and Gnauck 2009a).

The Sundarbans and the deltaic coastal region of Bangladesh are located in the south of the country and its geology with lying within the Bengal basin began 130 million years ago. The initial breakup of Gondowana land possibly occurred in early Cretaceous (130 million years ago) with a separation of India from combined Australian and Antarctica, the sea floor was created in what is now the Bay of Bengal (Anwar 1988).

Also the Bangladesh coast with including Sundarbans constitutes the low-lying landmass of the Himalayan river basin ecosystems (Iftekhar 2006). The formation of the delta plain commenced some 12,000 years ago when the sea level started to rise rapidly due to the melting of ice sheets to the north. About 6000 years ago, sea level rise slowed down and coastal plains started to form (Islam 2001; Iftekhar 2006). The large rivers especially the Brahmaputra, Meghna and the Ganges are playing an important role in the coastal region. Biogeographically, the coast is part of the Bay of Bengal large marine ecosystem (Nishat et al. 2002). The Ganges fresh water plays a vital role in coastal economy, floodplain fertility and keeps the balance of mangrove forest and wetland ecosystem services in south western coastal part of Bangladesh (Islam and Gnauck 2009b).

The coastal morphology is further characterized by different features like vast networks of rivers and channels, heavy water discharge carrying sediments, many islands in the coastal channels, strong tidal waves, cyclone and surges, physiographically funnel shape (Figs. 11.1 and 11.2). Also the Swatch-of-No-Ground canyon is located in the continental shelf about 24 km south of the Bangladesh coast (Figs. 11.1 and 11.2). Coastal mangrove landscapes and forest as well as wetland ecosystems are characterizing the south western region of Bangladesh coast (Islam et al. 2017).

The deltaic coastal region of Bangladesh within this Bengal basin is vastly influenced by the GBM-catchment as well as by the oceanic influences. The coastal length is 710 km and the coastal area comprises 47,210 $km^2$ with a population of 36.8 million (BBS 1979, 1981, 1985, Islam 2016). There are existing 19 coastal districts, which are including the coastal region such as Jessore, Narail, Satkhira, Khulna, Bagerhat, Gopalganj, Shariatpur, Chandpur, Pirojpur, Jhalokati, Barguna, Patuakhali, Barisal, Bhola, Lakshmipur, Noakhali, Feni, Chittagong and Cox's Bazar (Figs. 11.2 and 11.1) (Islam et al. 2017). The coastline of the Ganges delta extends from the mouth of Hoogly-Bhagirathi river in the west to the mouth of the Padma-Meghna river in the east (Figs. 11.1 and 11.2) (Rob 1998). The coastal area of the delta is confined roughly in an area between longitudes 80° 0′E to 91° 0′E and 21° 30′N to 22°

[2] For instance published papers in journals and books.

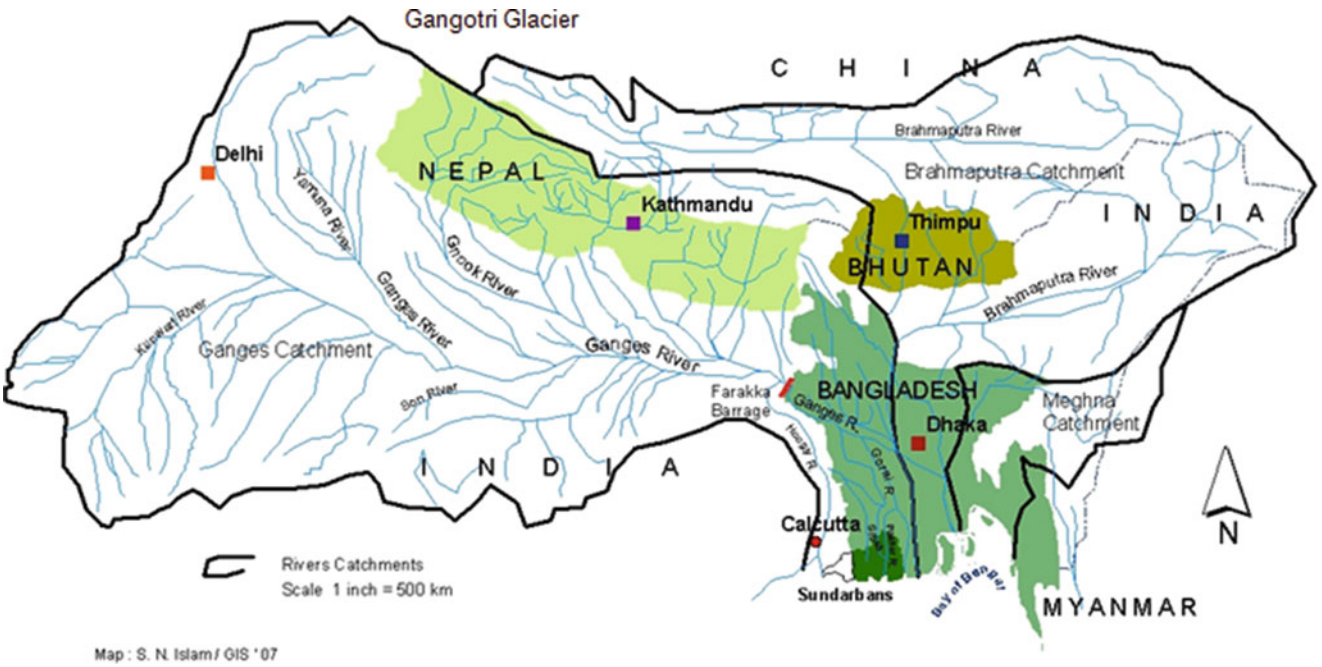



**Fig. 11.1** Geographical Location of the Sundarbans Mangrove Wetlands in Ganges-Brahmaputra-Meghna-Rivers Catchment Area, Bangladesh (Map Source: Islam and Gnauck 2008)

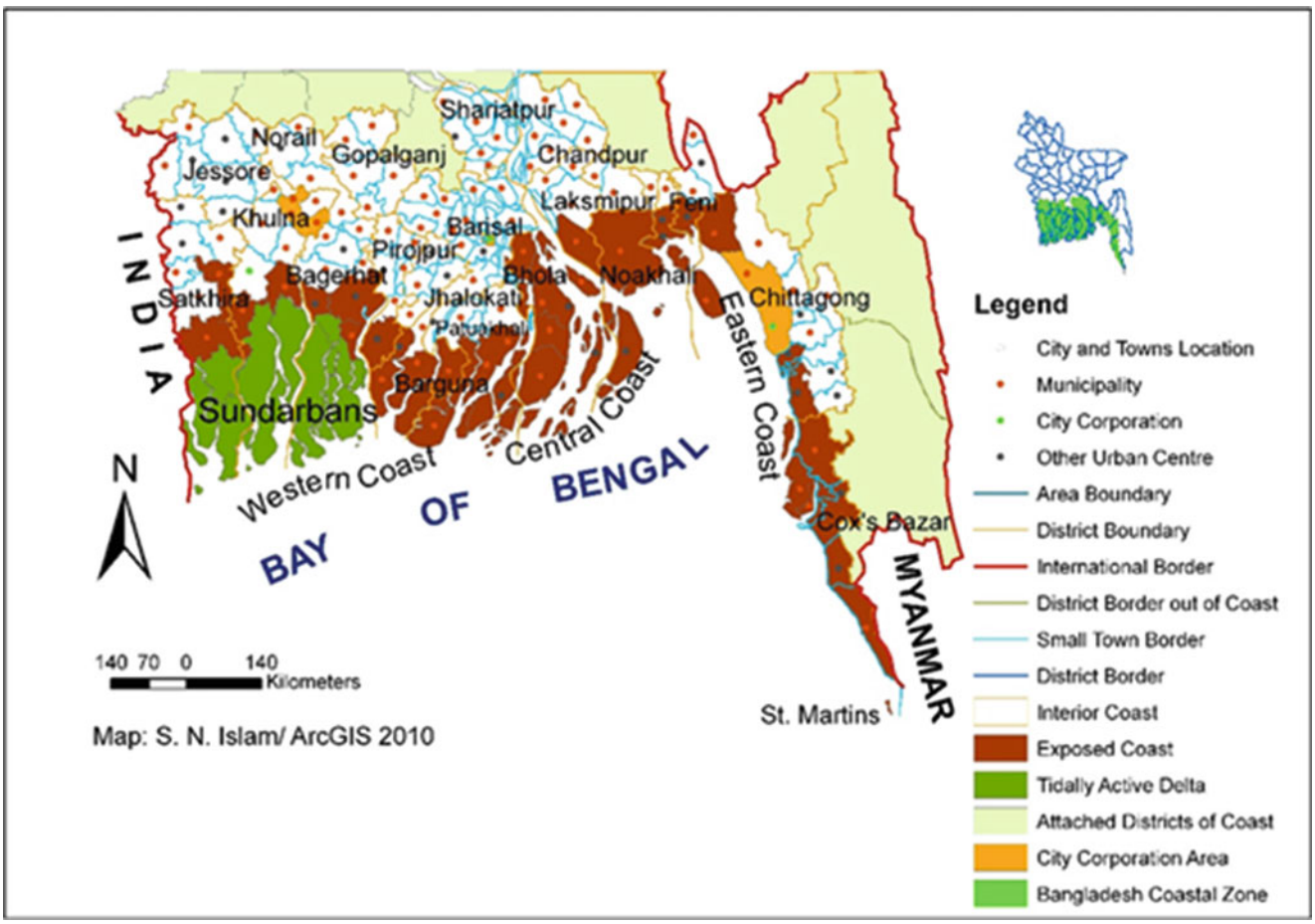



**Fig. 11.2** Coastal Morphology of Sundarbans Mangroves and Surrounding other Ecosystems in Bangladesh (Source: Islam 2010)

30′N latitude. The Sundarbans implementing coastal area of Bangladesh is deltaic active and hydrologically dynamic. The coastal areas of Bangladesh have been defined and categorized by the Coastal Area Resource Development and Management Association (CARDMA) in three different types of coastal regions on the basis of physiographic characteristics. These three divisions are: (1) the Eastern Region, (2) the Central Region and (3) the Western Region (Figs. 11.1 and 11.2). The eastern coastline is extending from the Big Feni River to Badar Makam along Chittagong, which is regular, unbroken and protected along the sea by mud flats and submerged sands. For instance the Cox's Bazar sand beach, which is about 145 km long, is part of this coastline (Figs. 11.2 and 11.1).

The central region runs east from the Tetulia River to the big Feni River estuary and 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 for this regions characteristic, heavy sediment input, formation of new *chars* and river bank erosion and accretion. The western region covers the coastline westward from the Tetulia River to the international boundary located at the Hariabhanga River (Figs. 11.1 and 11.2). This region is mostly covered with dense mangrove forests with having a reduced river bank erosion. The rivers of the region are mostly stable; land accretion does not occur massively (Jalal 1988).

The coastal regions of Bangladesh are categorized by three types of divisions based on the physiographic and ecological characteristics, from which the first one of the Atlantic Type inhabits the Sundarbans Natural World Heritage Sites perimeter: this western region is part of the Ganges deltaic floodplain, which includes the Sundarbans as being largely covered by mangrove forests. This western part of the coast is more stable than other parts of the coastal region. This category is comparable to the Atlantic coastal characteristics (Figs. 11.1 and 11.2).

Next to this Atlantic Type or Western (coastal) Region the other two categories of the coastal region are named Central Region[3] and Pacific Type[4] or Eastern Region (Figs. 11.1 and 11.2).

The GBM systems further attributes, which influence the more or less vulnerable characteristics of the Sundarbans mangroves, are such as being discharged through the low-lying area of the central coastline, heavy sediment at inputs from the rivers result in a morphologically dynamic coastal zone. The central region has deltaic characteristics. So the GBM Rivers discharge is about 1.5 million $m^3/s$ during the peak period (Hasan and Mulamoottil 1994).

## 11.5 Sundarbans Natural World Heritage Site

The Sundarbans Natural World Heritage Site is the one natural World Heritage site in Bangladesh next to two cultural World Heritage sites[5] with having a perimeter extent of 139,700 hectares (Islam 2003). The Bengali meaning of the Sundarbans is 'Beautiful forest'[6] and its principal tree species 'Sundari' or *Horitiera fomes* might be one of the reasons for the in this way named mangrove forest area (for further theories comp. Islam 2003).

Being located in the coastal zone, it can be stated that the coastal zone is a large and diverse area comprising a rich array of social, economic and environmental resources (Iftekhar 2006), which is applicable and influencing the Sundarbans in the same way. The influencing grade, which is also an important factor for vulnerability and degradation state evaluations (comp. Chap. 6.1) in the Sundarbans, can be estimated within the following facts of the Bangladesh coastal zone: (1) the coastal zone provides a natural and cultural heritage, the Sundarbans natural world heritage site, indigenous life style, and (2) tangible cultural heritage as well as (3) intangible cultural heritage and historic events. It further contains (4) natural resources that are a natural inheritance of immense economic, cultural and intrinsic value. (5) Coastal communities enjoy the coastal resources such as mangrove forests, indigenous cultural events, sand shore beaches, sun and the eco-tourism in the Sundarbans natural heritage site. (6) There are lots of cultural activities in the coastal region, which are dependent on coastal environment and its elements. (7) A total number of 600,000 people are employed to be about for 6 months. Besides this fact 120,000 tourists visit the Sundarbans heritage site yearly and 50,000 people work daily (Islam 2003).

Also being part of the estuary of the GBM Rivers catchment, the Sundarbans Natural World Heritage Site is the largest area of still functioning mangrove forest with spanning a spatial extent of 1 million hectares in South-West

[3] ***Central Region:*** The Ganges-Brahmaputra-Meghna (GBM) River systems fall into the Bay of Bengal through the Meghna estuary. The Meghna estuary is located in the central region of the coastal area of Bangladesh. The central region is more unstable and most vulnerable. Coastal char formation, river erosion and accretions are the regular activities and building up the character of region (Figs. 11.1 and 11.2).

[4] ***Pacific Type:*** The eastern region of Chittagong specially is a narrow strip with a long sandy beach in Cox's Bazar, known as Eastern Region. It is a long strip until Teknaf and St. Martins Coral Reef Island. The eastern part of Bengal coastal region is a hotspot of biodiversity and displaying coastal narrow floodplain and mountainous characters. This eastern region has Pacific characteristics (Figs. 11.1 and 11.2).

[5] The cultural World heritage sites are the Historic Mosque City of Bagherat (1985) and the Ruins of the Bhuddist Vihara at Paharpur (1985) (Islam 2003).

[6] 'Sunder' means 'beautiful' and 'ban' 'forest' (Islam 2003).

Bangladesh and South Eastern portion of the state of West Bengal in India (Islam 2003). This massive area of mangrove forest inhabits 75% of its protected site in Bangladesh and 25% in India (Islam 2003).

The most fascinating and picturesque mangrove forests of Sundarbans can be observed at the southern extremity of the Gangetic delta and to the northern apex of the Bay of Bengal within the districts of Shatkhira, Khulna and Bagerhat (Islam 2003).

The mangrove forests of the Sundarbans Natural World Heritage Site cover an area of 6017 $km^2$, of which 4143 $km^2$ is located on land and the remaining 1874 $km^2$ are within water such as in form of rivers, canals and creeks of widths varying from a few meters to several miles (Islam 2003). The Sundarbans mangrove forests constitute about 51% of the forest area of the country of Bangladesh (Islam 2003).

## 11.6 Vulnerability and Degradation of Coastal Mangrove Ecosystems in the Sundarbans Region

The Sundarbans Natural World Heritage Site is part of the continental shelf of Bangladesh coast, which has to be observed for estimating a vulnerability and degradation state in an entire and non-separated way. A secluded assessment of the protected site would not bring forward integrative solutions: so this continental shelf of Bangladesh coast is about 66,000 $km^2$ with having coastal water being very shallow with less than 10 m depth and covering about 24,000 $km^2$ as well as up to 200 m depth and covering about 70,000 $km^2$. The area of an Exclusive Economic Zone (EEZ) is about 1, 64,000 $km^2$ which is larger than the land area of Bangladesh with about 1,47,570 $km^2$ extent (Islam 2016; Islam et al. 2017). The sector contributes 22% of the total animal protein intake of the country. Especially this sector is most prestigious in order to find optimized and less conflicting (land use) planning solutions in order to strengthen the protection against proceeding vulnerability and degradation as well as to give benefits to this sector (Islam 2016; Islam et al. 2017).

The rise of a vulnerability or degradation grade as well as general damages of coastal ecosystems such as the unique Sundarbans Natural World Heritage Site poses a direct threat to human, flora and fauna survival in the coastal region in Bangladesh. Therefore such negative impacting processes disturb in sorts of a balanced sustainable development: primarily coastal resources are an important economic and socio-cultural source of both food and income. In correlation to a further rise of the vulnerability or degradation grade in coastal zones and within or at its boundaries of the Sundarbans, a critical situation arises for business as well as for ecology and biodiversity through ports, industrial development and – from that businesses partially influenced – lower developed or disturbed coastal-marine biodiversity resources (Fig. 11.2). In recent years coastal areas such as Sundarbans are also becoming more attractive for tourism and recreation purposes, which are giving a further driving force for a higher vulnerability or even degradation process. Fish and sea food are primary sources of animal protection in the coastal region (Tan et al. 1997. In the coastal region of Bangladesh and especially within already degraded parts of the even more extended Sundarbans mangroves (comp. Islam 2003), shrimp farms are densely concentrated and created natural disasters, which have cost thousands of lives. The rise of the vulnerability grade, degradation or even the complete destruction of mangroves also alters the regional water system and coastal habitats, affecting fisheries coastal ecosystem balances and climate stability (Islam 2003, 2016; Islam et al. 2017), which is bringing up a doubled negative loop in direct, cumulative or synergistically impacting coastal areas and the Sundarbans mangroves.

All of these effects further on reduce the fertility of land located in nearby areas (Biksham and Andrea 1996) and so also the Sundarbans Natural World Heritage Site. It is estimated that 90% of all marine organisms spend some portion of their life cycle within mangrove system (Adeel and Pomeray 2002). The Sundarbans mangrove forests furnish ecosystem services, which are made all the more valuable within times of climate change. They protect coastal communities from cyclone and storm damage, and this function may become even more important as climate change intensifies. Globally, mangroves are being cleaned or damaged at the alarming rate of 1–2% annually and in Bangladesh case it is the same. The Chakoria Sundarbans mangrove forest of Cox's Bazar in Bangladesh was already cleaned up one decade ago: the area was occupied by shrimp culture and the vulnerability and degradation grade raised with visually looking like a saline desert. The Challenge of coastal environment and water resources management in the Sundarbans Natural World Heritage Site as well as in the entire country of Bangladesh is to identify the trends impacting on coastal and mangrove resources, balance the multiple and competing demands and respond with strategies to achieve sustainable management in the coastal areas (Islam et al. 2017).

### 11.6.1 Vulnerability of Mangrove Ecosystem and Biodiversity

The vulnerability of mangrove ecosystems has to be understood in context of the definition of a coastal zone, in which mangrove ecosystems are placed: a coastal zone is the area on both sides of the actual land-sea interface, where the influences of land and water on each side are still in

determining factors-climatically, physiographical and ecologically (Ferdra and Feoli 1998). Also the location of the landward boundary of the coastal zone, which implements functions of three basic geophysical processes, is important for estimating vulnerability factors of mangrove forests: tidal fluctuations; salinity; and risk for cyclone and storm surges. The coastal zone of Bangladesh, which is being affected by these processes, cover an area of 47,210 $km^2$, or 32% of the country with serving as landmass of 19 districts (Fig. 11.2) and abound 36.8 million people, of whom 29% represent the population living in the coastal zone (MoWR 2005; Goodbred and Nicholls 2004; Islam 2016).

A higher vulnerability amplitude for Sundarbans mangrove forests and wetlands is coming from the fact that the bay of Bengal is affected by Tsunami incidences, for which the Sundarbans region is placed within the moderate Tsunami vulnerability belt (comp. Islam 2007). Further influencing processes for a higher predestination of vulnerability is the Sea level rise in general or the human influence through land use such as others. Up to that the coastal zone is highly affected by high spring tides when water is saline during the dry season (Islam and Gnauck 2007a, b). Also the coastal areas are highly prone to cyclone induced storm surges that bring about the most catastrophic damage here (Chowdhury 2009).

Next to the geomorphological, abiotical influences also other biotical influences next to the already named human land use habits are giving impacts to the vulnerability stage of the Sundarbans Natural World Heritage Site. Some abiotical facts are combined to the characteristics of the Ganges-Brahmaputra-Meghna (GBM) rivers system, which is the largest river system in the world and is passing through Bangladesh on its way to the Bay of Bengal and carries sediments 1.8–-2.4 billion tons (Nishat 1988). These facts are subject to ongoing coastal dynamic processes being generated by the river flow, tide and wide actions and leading to vulnerability enhancing processes such as accretion and erosion in the coastal area of Bangladesh (Nishat 1988; Islam et al. 2017).

Besides there are some other delineates of the coastal region, which are high salinity, tidal waves, especially the influence of shrimp cultivation, and administrative management of the coastal region.

### 11.6.2 Degradation of Mangrove Ecosystem and Biodiversity

The salinity investigation results show that the south west Bengal coastal regions and in these the Sundarbans Natural World Heritage Site are carrying the highest rate of water salinity which is unbalancing the coastal ecosystem and general ecology. According to salinity approximation this high rate is harmful to rural and urban biodiversity as well as for the species of humans and their urban drinking water (Fig. 11.3) (Islam et al. 2017).

The Fig. 11.4 demonstrates the water salinity intrusion trends in the south and southwest region of the Ganges deltaic region, which includes the entire Sundarbans mangroves (Islam et al. 2017).

**Fig. 11.3** The anthropogenic influences on coastal forests and wetlands in the Sundarbans mangrove in Bangladesh (Source: Islam and Gnauck 2007a)

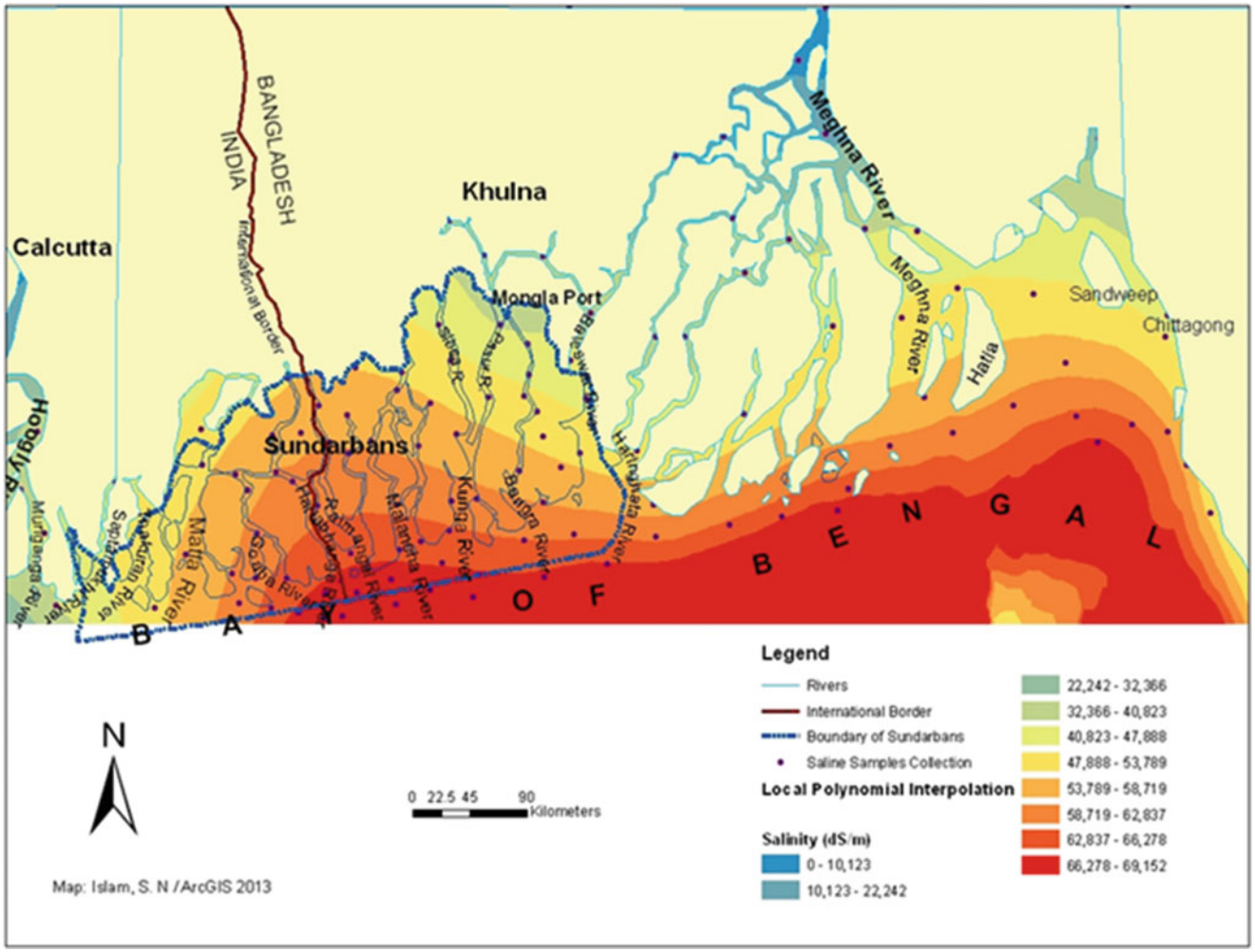



**Fig. 11.4** The Salinity intrusion pattern in the Bengal coastal region (Source: After Islam 2014)

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 effected 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 Southwest coastal deltaic regions are under threat for ecosystems and coastal rural and urban ecosystem goods and services. Also several observed districts face the greater challenge of higher salinization intrusion by comparing the data of an intense of affected land in hectare from 1973 and 2000 (comp. Sect. 7.1, Table 11.1) (Islam and Gnauck 2007a, b).

Especially the coastal mangrove and agro-biodiversity loss is a common scenario in the Ganges-Brahmaputra-Meghna Rivers deltaic region between Bangladesh and India. The Fig. 11.3 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 and wetland water and soil are rapidly degrading due to high saline water intrusion and anthropogenic influences (Figs. 11.3 and 11.4).

**Table 11.1** The coastal land area affected by high salinity intrusion (in1973 and 2000)

| Districts | 1973 (ha) | 2000 (ha) |
|---|---|---|
| Patuakhali | 115,000 | 139,000 |
| Barguna | 103,000 | 104,000 |
| Bhola | 40,000 | 93,000 |
| Pirozpur | 20,000 | 28,000 |
| Barisal | 8,000 | 10,000 |
| Jhalokhati | 1,500 | 3,000 |

The study also found that the mangrove reduction rate is about 45% in both countries (Bangladesh – India). Deforestation is raising and land-cover is changing due to shrimp farming, salt farming, agricultural land extension, urbanization extension and settlement development (Adel 2001, ESCAP 1988, Milliman et al. 1989). These development processes are adversely, affect coastal fish production and lead to a loss of agrobiodiversity and coastal floodplain biodiversity and of livelihood, which means to negatively

influence 3.5 million people, who are dependent on natural resources in the coastal region in Bangladesh (Miah 1989, Helcro 1993, Anon 1995). The mangrove wetland ecosystems are dependent on the water and soil salinity. Almost all mangrove forests need a freshwater supply from an upstream source. In the Sundarbans Ganges deltaic coastal region the two potential rivers such as the Passur-Mongla and Chunar-Munchigannj are carrying the high rate of salinity intrusion. The Fig. 11.4 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 southwestern region of the Sundarbans mangrove wetlands regions. The salinity rate was 42,000 dS/m in 2003, whereas in 2010 the salinity rate is 53,000 dS/m in the Passur-Mongla river point. On the other hand, the southwestern corner is showing the highest rate of water salinity in 2010, which is over 53,000 dS/m (Islam et al. 2017).

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 (Islam and Gnauck 2009a, b) as well as for the mangrove ecosystem and biodiversity in general. And already the coastal mangrove and wetland ecosystems have been recognized as a driving force for biodiversity conservation and coastal urban socio-economic improvement (Nishat 1993; Ahmed and Falk 2008; Islam et al. 2017).

Sixty six different species of mangroves (comp. Fig. 11.5) are growing in Sundarbans where 70 species have been recorded in the world, 12 species of plants and animals already vanished and Javan rhinoceros, Single horn rhinoceros, Water buffalo, Swamp deer, Mugger crocodile, Gaur and Hog deer are extinct animals (FAP4- FPCO 1993, FAP4-FPCO 1999).

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). Therefore, coastal urban wetlands biodiversity is facing serious challenges from salinity intrusion, environmental changes and anthropogenic impacts (Sarkar 1993; Sarker et al. 2003; Nair 2004; Ahmed and Falk 2008).

The mangrove forest and wetlands in the coastal region include rivers, estuaries, mangrove swamps, marsh (*haor*), oxbow lakes (*baor*) and *beels*, water storage reservoirs, fish ponds, and some other lands are also facing the similar environmental problems (Khan 1993; Hughes et al. 1994; Gopal and Wetzel 1995; Islam and Gnauck 2008; Islam et al. 2017). In such problematic complicated situation the smart-use of natural resources and salinity desalination processes can solve the coastal floodplains biodiversity and ecosystem problems in the Ganges-Brahmaputra coastal surface areas in Bangladesh.


**Fig. 11.5** The mangrove vegetation and biodiversity in the coastal wetland areas in Sundarbans region in Bangladesh (Source: Islam et al. 2017)

## 11.7 Sundarbans Mangrove Forests and Wetland Management Strategies

The coastal wetland resources are totally dependent on the upstream fresh water supply and availability in the coast, therefore some potential issues should be incorporated in national water policy in Bangladesh: if the present coastal wetland resource management strategies are analysed and compared with the national policies, it will show the real coastal wetland resource scenarios. There are 257 rivers in Bangladesh and they have an important role for supplying fresh water to the coastal areas (Islam 2007, Islam 2006), which would be most important for an optimized protection of the Sundarbans mangroves and the Sundarbans Natural World Heritage Site. So the Ganges-Brahmaputra-Meghna Rivers carry almost 6 million $m^3/s$ of water per day during flood season to the Bay of Bengal (Helcrow 1993, Goodbred and Kuehl 2000).

So the National water policy in Bangladesh (1999) is most important for optimized Sundarbans mangrove forests and wetland management strategies and also gives due importance on research and development. In article 3 the objectives of the national water policy (1999) has to be developed a state of knowledge and capability that will enable the country to design coastal water resources and wetland management plans by itself with economic efficiency, gender equity, social justice and environmental awareness. Article 4.15 of 'Research and Information Management' of this national water policy (1999) the involvement of public and private research organizations and universities should be strengthened and promoted and some specific objectives should be ensured such as (1) appropriate technologies innovation and implementation, (2) develop and promote coastal wetland and water resources management techniques and (3) produce skilled professionals for water resource management, which might also positively influence a better mangrove forest and wetland management.

The Ganges-Brahmaputra-Meghna Rivers carry also 13 million tons of suspended sediment per day during flood season to the Bay of Bengal[7]; it is three times the amount of borne by the Mississippi River (Coleman 1969; Anwar 1988). So it can be recorded that erosion and accretion are common phenomena in the coastal zone, where nearly a billion tons of sediment are brought by the rivers. About two thirds of these sediments are discharged into the Bay of Bengal, while the rest contributes to the formation of new land and islands (Iftekhar 2006). However river bank erosion is a severe problem also in sorts of mangrove forest and wetland management. The annual rate of erosion in the Meghna river estuary alone is around 3199 ha/year (Islam 2006). Aspects of the sedimentary history of the Bengal Basin since ca. 9000 years. BP can be interpreted from data provided in this study.

It is also undoubtedly true that the Ganges-Brahmaputra-Meghna River system has been carrying sediments from upstream and depositing them in the basin, but their depositional environment needs to be considered (Islam 2001). The Fig. 11.6 shows a model of integration of coastal mangrove forests and wetlands in the Bengal coastal region in Bangladesh.

Water related sectors such as agriculture, land use, water navigation sector, industrial sector, mangrove wetland ecosystems, forest sector, fisheries and livestock and coastal community livelihood are directly dependent on coastal mangrove forest and wetland resources (Fig. 11.6) (Islam et al. 2017).

Bangladesh produce 1 million tons of fishery products, which is more than twice of Indian aquaculture production per capita and Nepal, Pakistan and Sri Lanka lag far behind. The coastal Bangladesh aquaculture is emerging as a prime rural industry, contributing to employment, food security, poverty reduction and export earnings. The export of aquaculture products means for Bangladesh, to earn half a billion dollars per year, which is making them the country's second-biggest earner of foreign exchange after textile. All these water resources sectors and sub sectors are inter-connected for their own sectoral development and management. Therefore the coastal water resources sector is a potential sector in the coastal region and is serving as a driving force for sustainable development of the coastal region of Bangladesh.

In most developments, water resources management and sustainable livelihood discourses a need in form of integration at different levels are recognized and emphasized (Rahman 2003). The soil of the entire coastline is generally sediment deposit of the GBM and other rivers. Such soils are fertile, but recently it has been affected by high salinity intrusion. It has been estimated as being almost half of the coastal arable land and can be classified as saline zone. Saline affected areas such as the greater Khulna and Patuakhali districts are being the most affected areas in the coastal region of Bangladesh (Jalal 1988).

[7] It is estimated that some 1.5–1.8 billion tons of sediment is denounced in the Bay of Bengal per year (Nishat 1988; Rahman 1988) but Anwar (1988) and Jabbar (1979) mentioned that the mighty rivers Ganges, Brahmaputra and Meghna transports about 2.4 billion tons of sediments annually to the Bay of Bengal. Curray and Morre (1971, 1978) show an enormous sub aqueous delta beneath the Bay of Bengal formed by the sediment derived from the Ganges-Brahmaputra-Meghna Rivers, the Bengal Deep Sea Fan, and the largest deep sea fan in the world. Sediments deposited on top of the upper most peat are fluvial controlled. These are the sediments deposited by the Ganges-Brahmaputra-Meghna rivers system (Islam 2001).

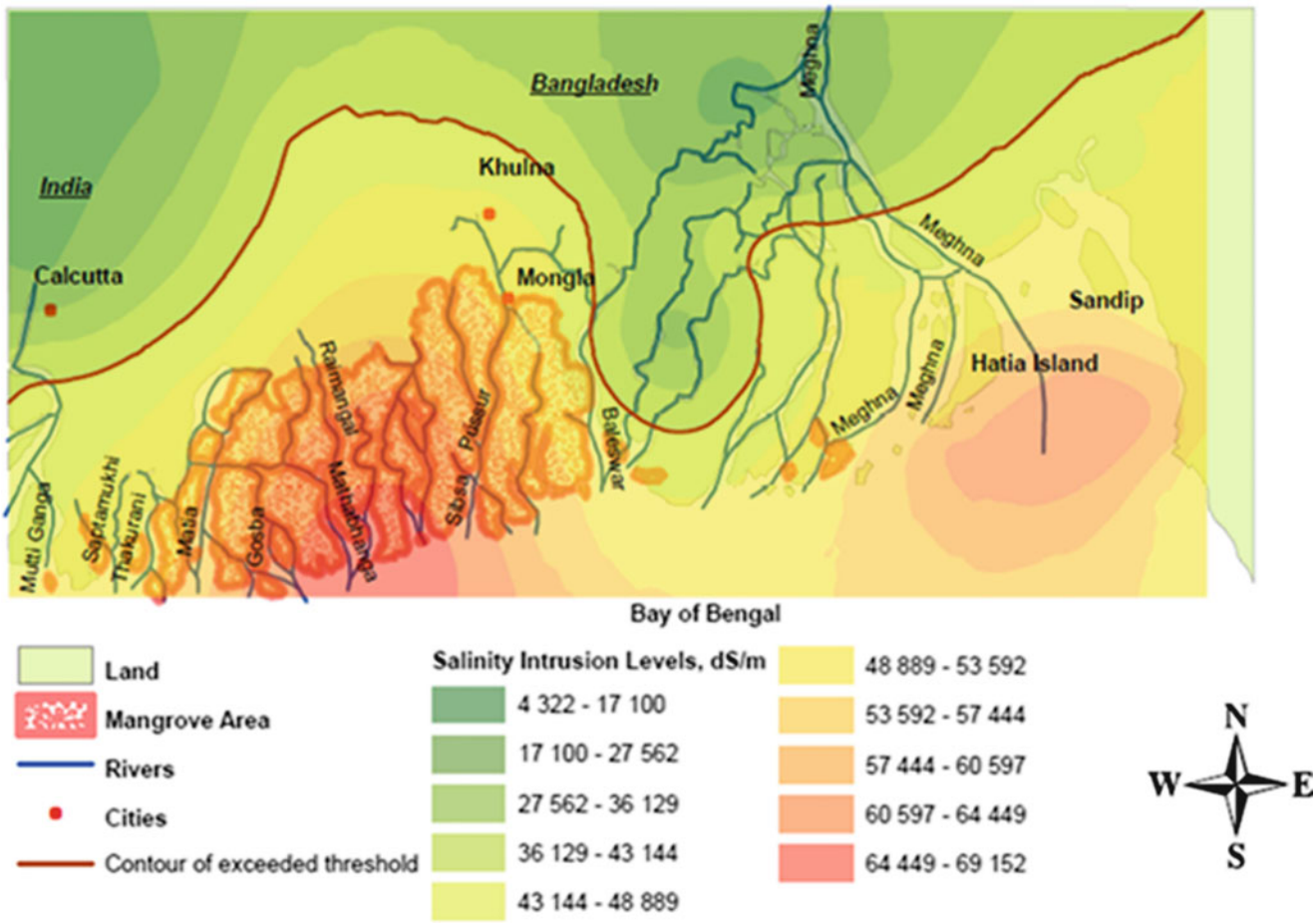



**Fig. 11.6** Interlinkage of coastal wetlands, water resources, ecosystem services and livelihoods (Source: Islam 2016)

### 11.7.1 River Water and Sediment Flow Characteristics Influencing the Coastal Mangrove Forest and Wetland Ecosystems

As already stated, from most importance for the further protective and sustainable development of Sundarbans Natural World Heritage Site is the provision of freshwater resources. So the river water cycle and flow dynamics are from greatest interest: the Ganges river is one of the freshwater sources, which itself receives over 60% of its discharge from its tributaries. The Gomti, Damodar, Yamuna Rivers, Mohananda are the major tributaries of Ganges Rivers in the Indian portion (Helmer and Hespanhol 1997), which has to be acknowledged for a continuing, advantageous development of the Sundarbans mangroves. The main distributaries of the Ganges River in Bangladesh are the Baral, the Gorai, the Arial Khan, the Bhairab, the Mathabhanga, the Kumar, Chitra and the Ichamati River (Miah 2001). Their average annual combined discharge into the Bay of Bengal is 100,000–140,000 $m^3/s$ carried by Ganges-Brahmaputra-Meghna (GBM) Rivers (EGIS 2000). As a whole the Brahmaputra (Jamuna) River carries water flow 60,000–100,000 $m^3/s$. The minimum water flow of the Meghna River is 3750 $m^3/s$ (Fig. 11.7) (Fedra and Feoli 1999, Goodbred and Kuehl 2000). The Ganges River is the major source of silt deposition and delta formation in the Bay of Bengal (Joseph 2006; Islam and Gnauck 2008). The Brahmaputra carries every year, about 600 million tons of sediments, with alluvial sand constituting large proportion (FAP 24 1996). The sediment is deposited in form of dunes in the river bed, which is about 350, in some cases up to 600 meters long and they can move very fast as 17 m/s (FAP 24 1996; EGIS 1997).

The Meghna Delta is the main output of the Ganges, the Brahmaputra and the Meghna to the Bay of Bengal (Chowdhury and Haque 1990). The sediment load is extremely high, with suspended sediment load during flood stage reaching as high as 13 million tons per day (Coleman 1969). The strong south Asian monsoon and high Himalayan source area supports one of the world's largest riverine sediment loads (1.8–2.4 billion tons annually) for the Ganges-

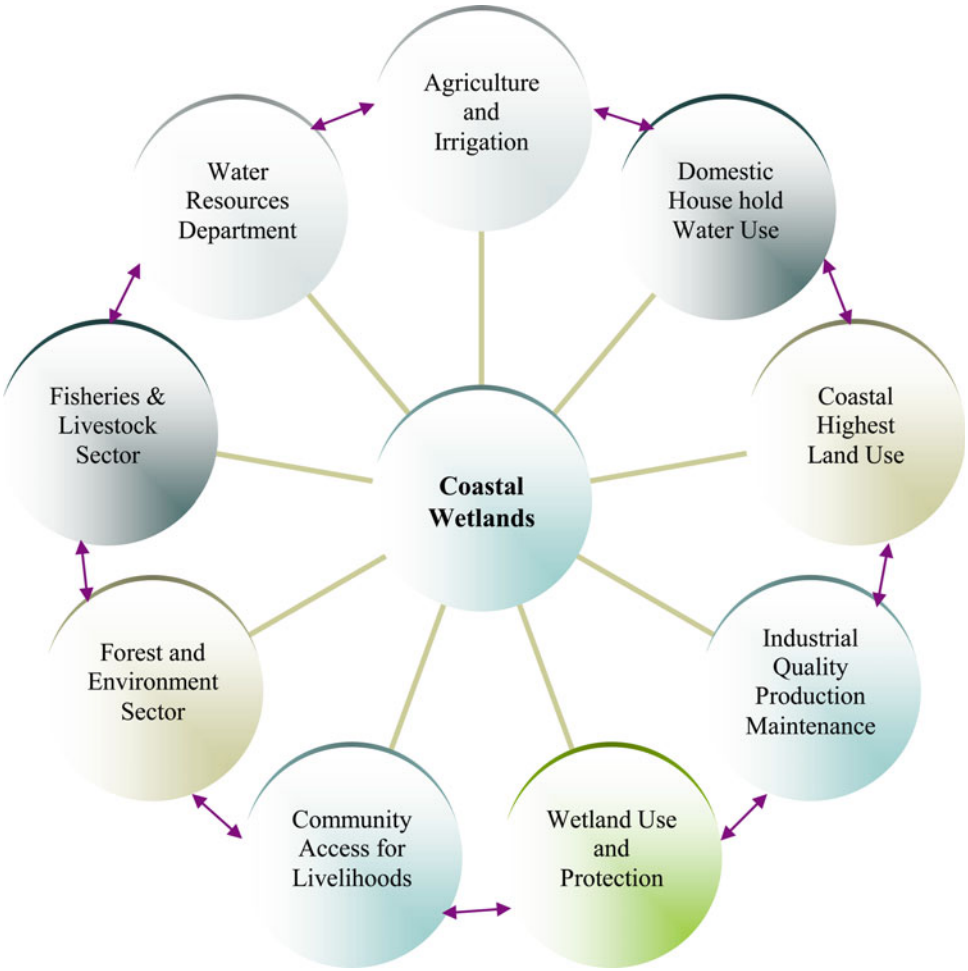



**Fig. 11.7** Major rivers annual water discharge flow in the Ganges Deltaic region (Data Source: EGIS 2000; Miah 2001; Goodbred and Nicholls 2004; CEGIS 2010)

Brahmaputra-Meghna dispersal system (Anwar 1988; Umitsu 1993; Goodbred and Nicholls 2004).

### 11.7.2 Present Threats for the Coastal Mangrove Forest and Wetland Ecosystems

The study finding has asserted that India's diversion of fresh water had resulted in a loss of biodiversity. This loss of biodiversity became three times more in Bangladesh in the year of 2007 than the already observed loss from 1976 (Islam and Gnauck 2009a, b). The observed species decline was already in 1976 negatively coupled with the rice output of 236,000 metric tons, which is further correlating with the just in before closed up construction of Farakka Barrage in India. The previous study result of EGIS (Environmental Geographical Information Services) from the Centre for Environmental Geographical Information Services (CEGIS) showed, that the water quality of Sundarbans region had been degraded in the dry season (February–June): 60% of the water of Sundarbans rivers are poor quality with an EC (Electrical Conductivity) dS/m is 5532; the other 40% show up a good quality with an EC of dS/m 2766 (Islam and Gnauck 2009a, b). Coastal water pollution such as oil spills are a new threat and could cause immense damage, especially to aquatic fauna, seabirds, mangrove biodiversity and coastal agricultural cropping systems. The yearly natural calamities, global warming and its impacts are also new challenges and threats for coastal food security and agro-biodiversity (Islam and Gnauck 2009a, b; Islam et al. 2017).

As being declared through an earlier soil investigation conducted by SRDI in 1970, soil salinity was mainly found in the Ganges tidal floodplain of the coastal region. The Ganges River floodplain and the peat basins areas were classified as being non-saline. Soil salinity occurred south of Khulna and Bagerhat districts. The surface and subsurface salinization is very common with saline water intruding into freshwater aquifers. Each year, a new area of 146 $km^2$ is affected by salinity, whereby in the same process a significant reduction in biodiversity is observed (Dutta and Iftekhar 2004). Salinity range was between 8644 dS/m and 17,288 dS/m. A rise of soil and water salinity has been noticed in 1975 when Farakka Barrage was constructed on the Ganges

River and withdrawal fresh water from the basin (Islam and Gnauck 2007a, b). At present soil salinity level has been recognized south of Khulna and Bagerhat town, where it ranges from 17,288 dS/m to 32,415 dS/m during the dry season (November–May). Soil and water salinity is rapidly increasing in the coastal region and currently, river water salinity moves up as far as Kamarkhali River port in Magura district (SRDI 2000; EGIS 2000; Islam and Gnauck 2008). The salinity trends are higher in the Sathkhira, Khulna, Bagerhat, Borguna, Jhalokhati, Potuakhali, Bhola and the southern part of Noakhali districts (Table 11.1).

The salinization trends are higher in the south western region of Bangladesh. These trends urgently have to be implemented while developing and finding management strategies for the Sundarbans Natural World Heritage Site. Within the gradually eastern region comparatively less saline intrusion in the coastal region can be recognized.

At present, tidal waves, surges and coastal flooding are common annual natural phenomena in Bangladesh (Islam 2001). Most coastal regions show uneven sediment compaction which is controlled by differential sedimentation rates, sediment composition, water content, depth of overburden sediment layers and tectonic activities (Greensmith and Tucker 1986; Islam 2001). A national strategy for coastal resource management in Bangladesh is necessary to identify and analyse the problems and opportunities for future development. A study of ESCAP (Economic and Social Council for Asia and the Pacific) in 1988 and GOB (Government of Bangladesh) have referred five sets of constraints to the development of a strategy for coastal water and wetland resource management in Bangladesh such as:

- Policy making and strategies' implementation
- Planning for coastal water and wetland resources maintenance
- Integrated coastal wetland resources management
- Coastal wetlands and marine resources uses and sustainability
- Local environmental and coastal ecological perspective and
- Lack knowledge of coastal wetland environment and better understanding (Jalal 1988).

The water and soil salinity penetration in the upstream area of the whole coastal zone is one of the main obstacles to maintenance mangrove forests and wetlands such as the Sundarbans mangroves and in the same way the water quality for drinking, irrigation and fisheries purposes. The shortage of upstream freshwater supply to the coast and tidal waves are facilitating to penetrate salinity intrusion (SRDI 2000). In the coastal belt are 81,000 ponds existing with scattered locations, which are the main source of freshwater supply for domestic consumption in rural areas. The quality of wetland's water is the major constraint in water supply (Jalal 1988).

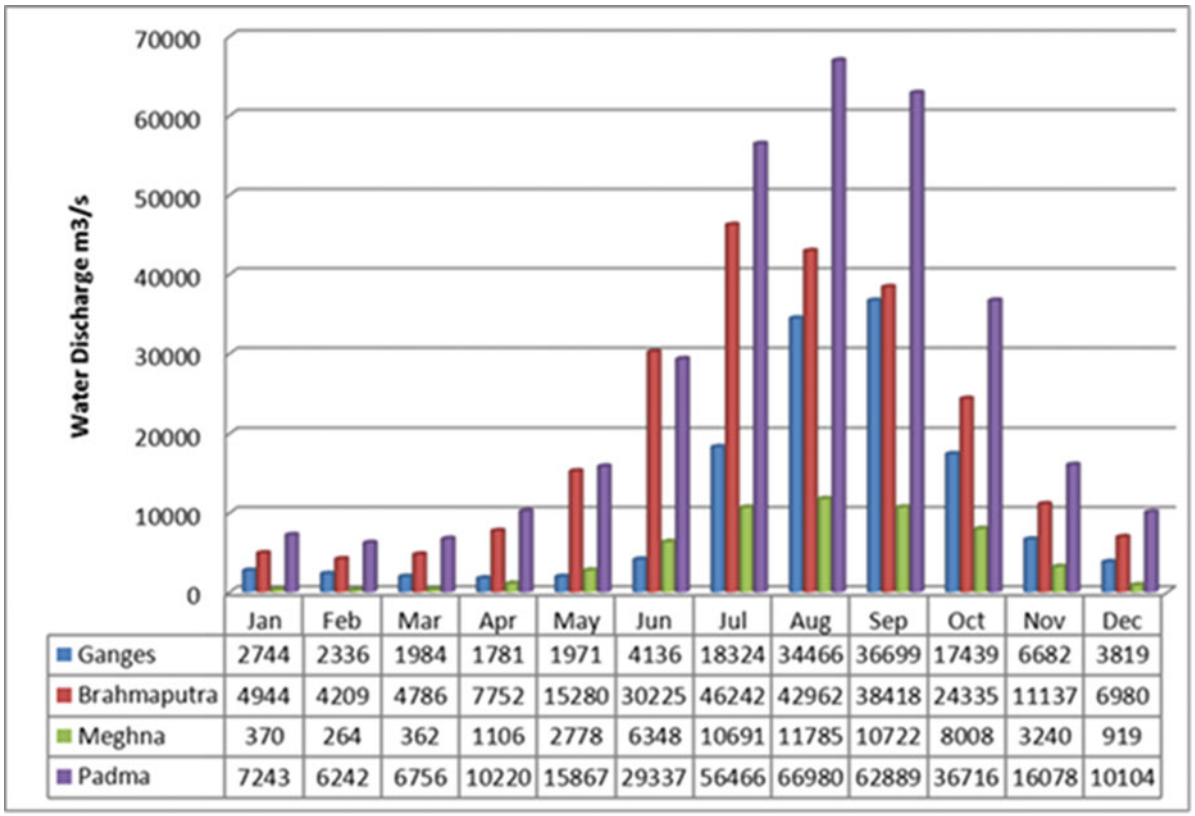
Another threat is correlated to the fact, that the coastal wetland lands are fertile for shrimp cultivation as the water is mostly saline. A total of nearly 150,000 ha were used by shrimp cultivation in the region, which is representing 11.8% of the land in the region respectively. Almost 60% of the biomass comes from agricultural residues in the coastal region. Around 200 industries in industrial zones of Chittagong discharge their untreated wastes to the Karnafuli River. Another 190 industries are located in three industrial zones of Khulna with discharging untreated toxic waste into the Bhairab River, which is carrying into the coastal region and therefore giving further threats to the Sundarbans mangroves. There are 50 coastal towns, which are located in the coastal region and are affected by high salinity intrusion in drinking water and arsenic contamination in ground water aquifers.

Beside these, there are two existing international ports situated in the coastal region. The ships at the ports have spillages of crude oil and discharge of ballast water, sewage from ships and other activities, which are causing severe coastal water pollution into the coastal marine ecosystems such as the Sundarbans mangrove forests and wetlands. The tourism activities in the coastal region of Bangladesh are also distracting water quality in the coastal region.

As a whole the Bangladesh coastal region is the most vulnerable coast in the world (Jalal 1988). There is none integrated management plan for the coastal natural resources or for the coastal communities existing. The coastal land cultivation, paddy and shrimp production policy is still dependent on the local initiatives. Freshwater flows, drinking water supply, water for irrigation and fishing are severely affected. Considering the present water resource management condition a newly policy framework guideline is essential to protect and maintenance the coastal water resources in Bangladesh and with it the Sundarbans mangrove forests and wetlands in the Sundarbans Natural World Heritage Site.

### 11.7.3 Sea Level Rise and Its Impacts on Coastal Region

Climate change and sea level rise, being induced by global warming, also compromise the ecological stability of the coastal zone; in sum, due to various natural and anthropogenic factors, the natural resource base of the zone is declining and the vulnerability as well as degradation grade is raising. Failing ecosystem productivity further degrades the quality of life for the local population (Dasgupta 2001) and all other floristic and faunistic species: relative Sea-Level Rise (SLR) movement has an immediate and direct effect on the coastal inter tidal ecosystems, particularly on




| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ganges | 2744 | 2336 | 1984 | 1781 | 1971 | 4136 | 18324 | 34466 | 36699 | 17439 | 6682 | 3819 |
| Brahmaputra | 4944 | 4209 | 4786 | 7752 | 15280 | 30225 | 46242 | 42962 | 38418 | 24335 | 11137 | 6980 |
| Meghna | 370 | 264 | 362 | 1106 | 2778 | 6348 | 10691 | 11785 | 10722 | 8008 | 3240 | 919 |
| Padma | 7243 | 6242 | 6756 | 10220 | 15867 | 29337 | 56466 | 66980 | 62889 | 36716 | 16078 | 10104 |

**Fig. 11.8** Climate change impacts in the coastal region of Bangladesh (Source: Akter et al. 2010)

vegetation. Arise of relative SLR decreases the influences of terrestrial processes and increases the influence of coastal marine processes (Islam 2001). The worlds' great deltas are among the most densely populated and most vulnerable of coastal areas, which are threatened by sea level rise (Broadus 1993). Global warming and sea level rise and vulnerability of coastal wetland ecosystems are factors that have to be considered the long term management strategy for dealing with the coastal mangrove forest and wetland issue also within the Sundarbans Natural World Heritage Site. 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). The global warming and climate change with its predicted sea level rise is further accelerating by global warming and therefore will cause a further 'Squeezing' of the natural tidal land. In Bangladesh case a sea level rise of 3 mm/year with being predicted as occuring before the year of 2030 and a resulting inundation of 2500 $km^2$ or 2% of the land have been projected by IPCC (2007) and MoEF. About 20% of the net cultivable area of Bangladesh is located in the coastal and offshore island (Fig. 11.8).

A very recent study on the coastal area in Bangladesh by IPCC 2007 shows that the mean tidal level at Hiron Point is showing an increase of 4.0 mm/year, which is higher than the global rate. Soils in this area are affected by different degrees of salinity (Rahman 1988). 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. 11.8). The fact of climate change impacts are a new threat for the coastal area of Bangladesh (Fig. 11.8). In the case of Sundarbans mangrove and its World Heritage Site, sea level rise would result in saline water moving further into the delta, which would be the major threat for mangrove forest and coastal wetland ecosystems (IECO 1980).

The fate of the Sundarbans can be seen within different sea level rise and the potential impacts on environment: if 10 cm SLR will inundate, 15% of the Sundarbans will be affected; having a SLR of 1.5 m, about 17 million (15%) of the population will be concerned. The afflicted population will have to be displaced or getting homeless, whereas 22,000 $km^2$ (16%) of the land will permanently be inundated (Fig. 11.8).

The Fig. 11.8 shows a scenario with 3 m SLR, which would be even a worse scenario for Bangladesh with almost one third of the land –and for sure also the Sundarbans Natural World Heritage Site – could be inundated by saline water. The reduction rate of mangrove areas will be in between 50% to 75%, which would be even more harmful

for coastal ecosystems in the estuaries (IPCC 2007). Besides, other environmental problems will arise in the coastal belt such as (1) water pollution and scarcity, (2) soil degradation, (3) deforestation, (4) solid and hazardous wastes, (5) loss of bio-diversity estuary landscape damage and (6) river bank erosion, which will create a lot of new challenging problems for human livelihood in the coastal region. In such situation it will further create an unstable agricultural crop production, damaging fisheries, livestock and food security in the coastal riverine islands in Bangladesh. Therefore climate change impacts on coastal region such as on the estuaries in the Sundarbans will create new threats for estuaries ecosystems and landscapes.

### 11.7.4 Changes of Mangrove Biodiversity in the Bengal Coastal Region

The salinity investigation results show on the one hand a greater vulnerability as well as potential for further degradation and on the other hand, that the south west Bengal coastal regions are carrying the highest rate of water salinity. This is misbalancing the existing ecosystems and their inhabited ecologies. According to salinity approximation this high rate is harmful to rural and urban biodiversity as well as for rural and urban drinking water (Fig. 11.8). The Fig. 11.8 demonstrates the water salinity intrusion pattern in the south west region of the Ganges deltaic region, where 4 major cities and 136 small towns are located in the coastal region in Bangladesh. Most of the towns are affected through salinity intrusion and sea level rise impacts in the region. Therefore, the investigation results of salinity modelling in the Southwest coastal deltaic regions show that ecosystems and coastal rural and urban ecosystem goods and services are under threat. As a result, coastal mangrove and agro-biodiversity loss is a common scenario in Bangladesh and India. The mangrove reduction rate for instance is about 45% in both countries. Deforestation and land cover is changing due to shrimp farming, salt farming, agricultural land extension, urbanization extension and settlement development are adversely affecting coastal fish production and leading to a loss of agro-biodiversity and natural resources for coastal rural or urban biodiversity and 3.5 million people, who are dependent on a functioning coastal region in Bangladesh (Anon 1995).

Moreover a rich biodiversity of flora and flora support and contribute substantially to the socio-economic life of these millions of people in rural, remote areas of the world by providing opportunities of employment, food and nutrition, fuel, fodder, transportation and irrigation (Nishat 1993). The coastal forest and wetland resources in Bangladesh have suffered drastically from the impacts of growing human population, climate change and anthropogenic activities on natural resources. The water resources and mining resources are similarly used for an economic development. Furthermore natural resources are recognized as a driving force for biodiversity conservation and coastal socio-economic improvement (Nishat 1993; Ahmed and Falk 2008). So in the Ganges-Brahmaputra-Meghna floodplain alone approximately 2.1 million ha of wetlands have been getting lost due to flood control, drainage, and irrigation development (Khan et al. 1994). Therefore, coastal wetlands' biodiversity is facing serious challenges from salinity intrusion, environmental changes and anthropogenic impacts (Sarkar 1993; Sarker et al. 2003; Nair 2004; Ahmed and Falk 2008). The wetlands in the coastal region include rivers, estuaries, mangrove swamps, marsh (*haor*), oxbow lake (*baor*) and *beels*, water storage reservoirs, fish ponds, and some other lands with also facing the similar environmental problems named in before (Khan 1993; Hughes et al. 1994; Gopal and Wetzel 1995; Islam and Gnauck 2008). In such problematic, complicated situation the smart use of natural resources and salinity desalination processes can solve the coastal urban biodiversity and ecosystem problems in the coastal surface areas in Bangladesh.

### 11.7.5 Threatened Coastal Deltaic Forests, Forestry and Agricultural Crop Production

In the Ganges deltaic region of Bangladesh more than 60% people are dependent on agricultural crop production (Fig. 11.9). At present 30% of agricultural productions and 45% of mangrove forests are reduced in the coastal region due high to medium level of salinization.

The coastal region of Bangladesh is very important for the country because of natural resources, newly formed land area and mangrove forest, forestry, agricultural and fishery resources. A total of 6017 $km^2$ of mangrove forests is covering the perimeter of the Sundarbans Natural World Heritage Site (Islam 2003). These areas of the Sundarbans mangrove forests constitute about 51% of the forest area of the country of Bangladesh (Islam 2003). Comparing with the agricultural situation, a total of the Bengal coastal region with 47,000 $km^2$ of the land area is declared as coastal region where agriculture and aquaculture are the most popular and potential agro-crops and food production of the country. They are covering 34% of the country's food demand and a major portion of this 34% is placed within the coastal urban region.

The major role of mangrove forests and wetlands are their high nutrient factors and its retention/removal through a support for food chains, fisheries production. Also habitat for wildlife, recreation, natural heritage values, biomass production, water transport, biodiversity presentation and micro-

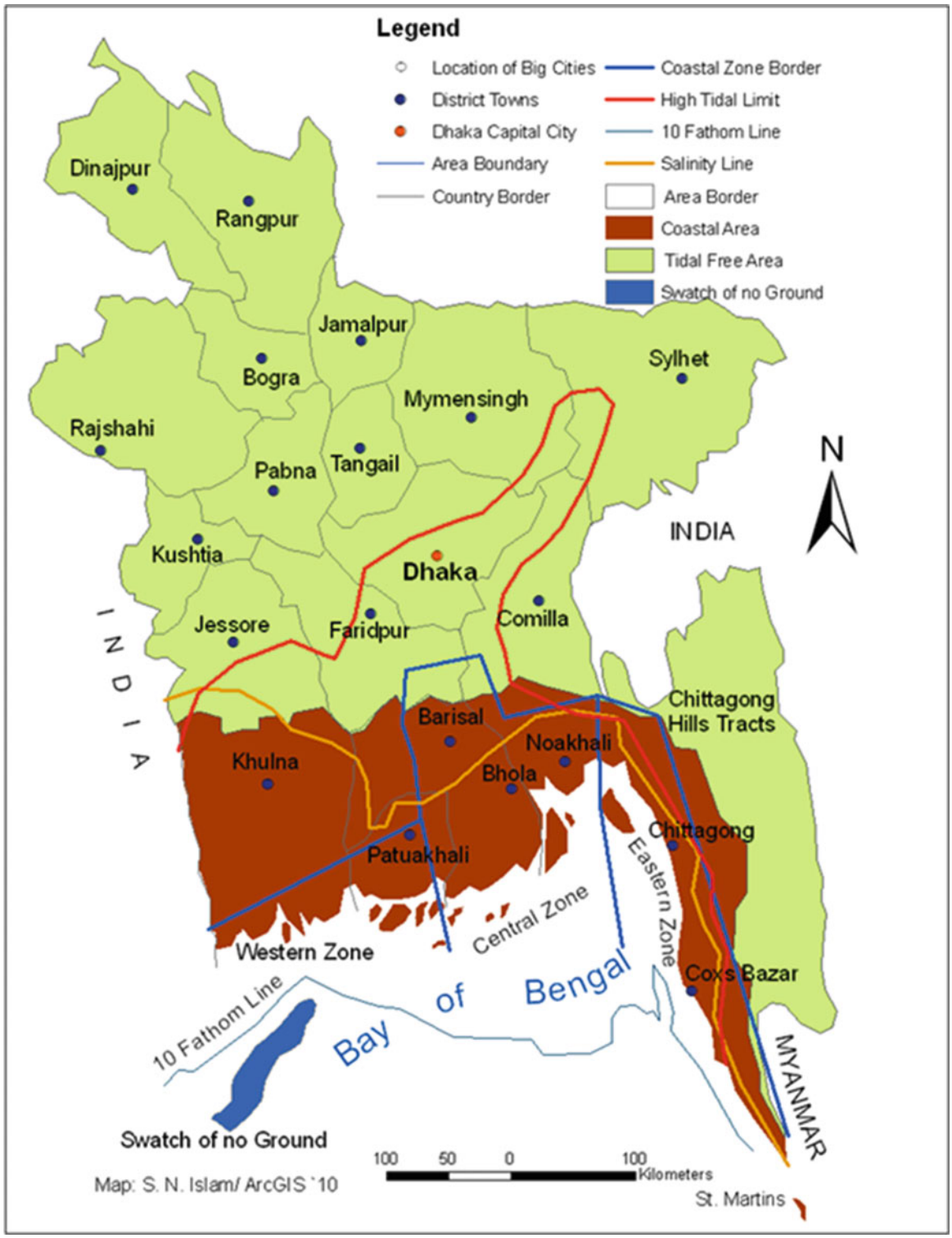



**Fig. 11.9** The lower Ganges-Brahmaputra-Meghna Deltaic coastal mangrove forests and wetlands region is affected by salinity intrusion (Source: Islam 2014)

climate stabilization are some further important ecosystem services being placed within these for forests, forestry and agriculture most important areas.

The Fig. 11.9 shows the water and soil salinity intrusion pattern in the south western Ganges deltaic region of the Bengal coast. There the salinity trend is imposing in the upstream areas from south direction to north direction.

In the north direction most part of the mangrove forests converted already to agricultural lands, which are now again converting from agricultural crops to shrimp cultivation due to high salinity intrusion. As a result the soil fertility of former forest or wetland areas and agricultural lands are losing its fertility.

The major cities like Calcutta are still located in the upper north and Mongla, Bagerhap, Sathkhira, Khulna are located under this salinity threshold line (Fig. 11.9). On the other hand most of the coastal towns in the deltaic region are also affected due to high salinity intrusion: the traditional urban vegetation and crops are also changing due to salinity intrusion in the urban areas of the Bengal coastal region. In Fig. 11.9 the red line illustrates the salinity thresholds line for agricultural crops and vegetation productivity.

The threshold line is indicating the contour of an exceeded threshold value (43,220 dS/m), which is harmful and is giving threat to normal forests, forestry or agricultural crop production and coastal urban vegetable production. Further on this line divides up the areas with a lower or high threat for safe drinking water availability in the coastal towns in Bangladesh.

So the coastal region of the Bengal delta of Bangladesh with its Bengal coastal region of 47,000 $km^2$ of land is now under threat for (mangrove) forests, forestry, agricultural crop production and rural and urban biodiversity conservation (Islam et al. 2017). Also the present condition is penetrating the coastal rural and urban food security in case of a gradually reduction of agricultural productivity within the coastal region in Bangladesh and within the protected part of the Sundarbans mangroves.

## 11.8 Approach for Coastal Mangrove Ecosystems Management and Sustainability

The coastal water resource usages and maintenance is the fundamental management aspect for local communities also in the Sundarbans region. The fringing of this study identified a number of environmental obstructions for proper use, reuse and maintenance of their coastal natural resources. Most of the developing countries have not yet developed the coastal water and natural resources management policies and strategies. Therefore, shortage of upstream freshwater supply, saline water intrusion and climate change impacts on the coastal regions and here within the Sundarbans Natural World Heritage Site are the greater challenge for enduring mangrove forests, forestry and agricultural crop production with maintaining food security in the coastal region of Bangladesh. These preoccupations need to be recognized and each given due weight in order to integrate them into policy and decision making in coastal water resource management to fight against climate change impacts, loss of mangrove-biodiversity, food insecurity and poverty for ensuring sustainable development for the coastal communities as well as floristic and faunistic other species. This means to foster a development, which meets the needs of the present without compromising the ability of future generations to meet their own needs. For such development it is important to carry out a programme for making the people aware of the impending dangers and to develop along with them methods of coastal adaptation and migration to promote water resources management and proper use for food security in the coastal region of Bangladesh and especially within and at it outbounds of the Sundarbans mangroves while acknowledging and following the vulnerability adaptation framework.

Figure 11.10 is demonstrating a local level planning approach for sustainable local level natural resources management.

The model (Fig. 11.10) has been prepared based on the present situation of coastal mangrove forest and wetland resources scenarios in Bangladesh case. Considering the findings, this long-term management plan for a sustainable use of coastal water resources is necessary and is urgently needed (Islam et al. 2017).

This model could be implemented in the coastal region in Bangladesh or especially in the part of the Sundarbans Natural World Heritage Site as well as in other coastal regions, which have a similar character like Bangladesh. Besides such as following, some practical recommendations can be applied for a better management of coastal mangrove forest and wetland resources in Bangladesh:

- Therefore applied research, awareness raising education, monitoring and evaluation are the key potential issues of a successful coastal wetland resources management and conservation.
- An increase of salinity due to the lack of freshwater flows in the transboundary river basin has caused damage to the vast area of coastal region and its ecosystems. Adverse development initiatives should strengthen environmental stability and protect against further degradation.
- Upstream river water supply should be ensured for the coastal region in Bangladesh coast and the inhabited Sundarbans Natural World Heritage Site. Especially whenever Ganges water supply is a disputable problem between India and Bangladesh, therefore other rivers water and monsoon water should be harvested throughout for instance a reservoir in the upstream area and supply freshwater to the south western coastal region could solve high salinity problem (Begum 1987).
- A sharp rise in water levels generally begins in May and continues until July. Therefore, some potential steps

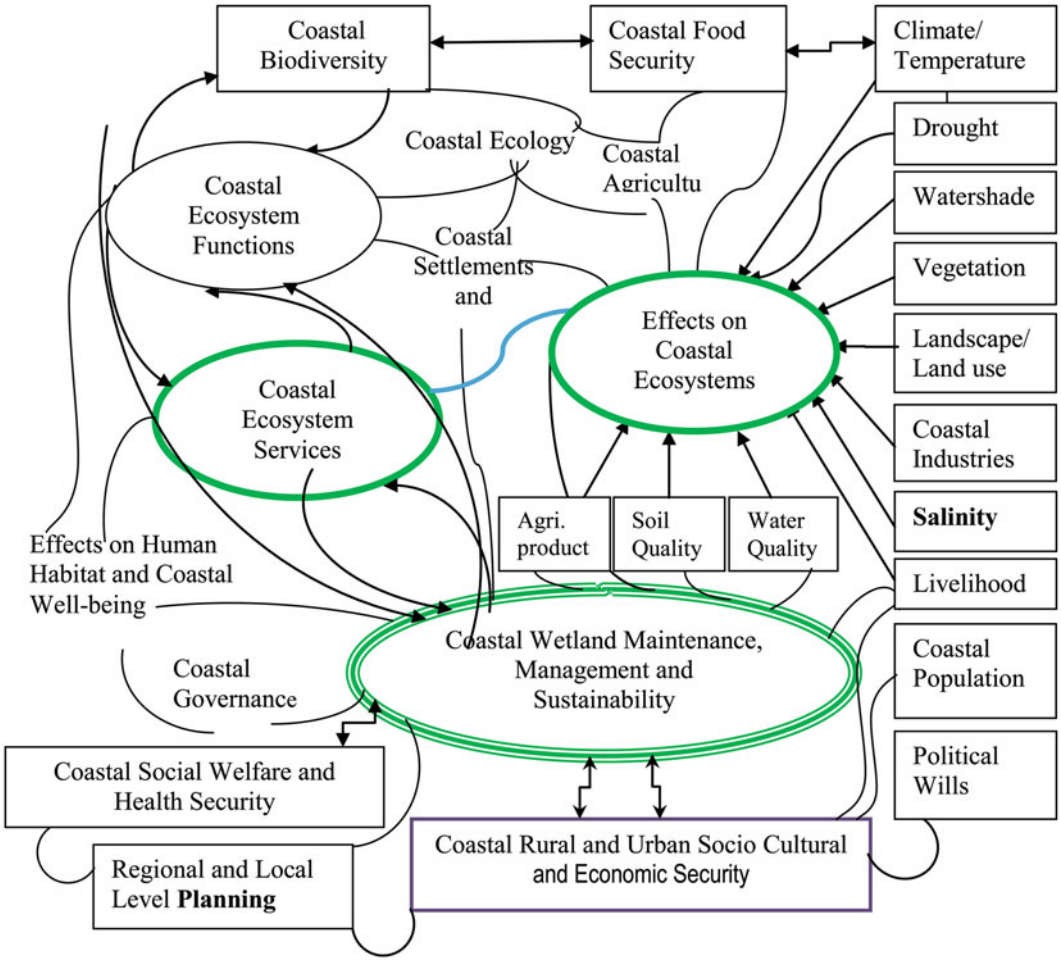



**Fig. 11.10** Model of Coastal mangrove forest and wetland resources protection, management and sustainability (drawn by the authors after Islam 2015)

should be taken into consideration for sustainable water resources management in the coastal region such as:

- Monitoring of ground and surface water quality and
- Modelling for its sustainable management of coastal mangrove forest and wetland resources.

The coastal community plays a further major role and becomes the key to success in integrated coastal mangrove resources management. It has been realized that coastal natural resources rely on the active participation of the coastal communities in protecting, maintaining and conserving their surrounding resources. Coastal community base management could be the best strategy in integrated coastal management that could ensure the involvement of the coastal society, and stakeholder in implementation stage. The indigenous coastal community is ecologically friendly and is an important source of intellectual asset in management of the coastal ecology (Hidayati 2000). The community, as the prime user of the coastal mangrove forest and wetland resources, should be involved and local technology should be considered within protecting practices and maintaining mangrove forest and wetland resources in the coastal region of Bangladesh and especially in the Sundarbans Natural World Heritage Site.

## 11.9 Conclusions and Recommendations

Coastal mangrove forests and wetlands can be considered as driving force for community social and economic enhancement. They have the ability to focus tremendous energy and to generate significant creative and economic betterment. In general, the country's coastal mangrove forest and wetland natural resources as well as the ecosystems are degrading due to anthropogenic influences and natural calamities. Considering the scenarios of the Ganges-Brahmaputra deltaic coastal zones of Bangladesh have great importance for the country's economy, industrial, ecological, socio-economic and cultural context. Moreover the Sundarbans coastal mangrove forests and wetlands support rich biodiversity and are contributing

substantially to the livelihoods of millions of people through creating opportunities of employments. The climate change impact has been notified as being an additional negative impact on coastal mangrove forests and wetlands as well as the local communities and stakeholders in the Ganges-Brahmaputra rivers deltaic region and its Sundarbans Natural World Heritage Site in Bangladesh.

The coastal region of Bangladesh encompasses about one fifth of the country's landmass and supports livelihood of 36.8 million people. The entire region with its Sundarbans Natural World Heritage Site is becoming more vulnerable due to natural and anthropogenic causes. Growing anthropogenic and climatic impacts have been found to put multifarious adverse impacts on coastal water resources, environmental and livelihood of the inhabitants of the coastal region. It is estimated that the requirement of the Ganges freshwater supply to the Sundarbans is 49 MAF and other rivers are also supplying the similar quantities of surface water to the Sundarbans. Any endeavour through to be suitable for the wellbeing of the people as well as for the coastal environment, has to be viewed with options in considering the socio-economic and cultural traditions of the society. Any particular adjustment to be included in the final plan ought to be within the technological capability of the people.

The study findings show that water and soil salinity intrusion is a severe threat for Sundarbans Natural World Heritage Site and its implemented mangrove ecosystems and its services such as agricultural crop production as well as coastal settlements and population. National and international political commitments and wills should be ensured properly. Therefore an integrated coastal natural resource management policy and a guideline framework for livelihood is necessary and urgently needed for Sundarbans Natural World Heritage Site and its surrounding Ganges – Brahmaputra rivers deltaic region in coastal Bangladesh.

Considering the influence, problems, prospect and their impacts on socio-economic condition of the coastal community and on the ecosystems of coastal natural resources, the strategies and intervention in planning is necessary. There is a potential realization that effective coastal water resources management at local level is an essential and appropriate management structure, which should be developed.

The study would suggest that most mangroves along the coast of Bangladesh would disappear under sea-level rise scenarios when rate of rise up to 1.5 cm year$^{-1}$ have been predicted. So Sundarbans Natural World Heritage Site and its surrounding would be under greatest threat and danger (has been seen in Fig. 11.8). Therefore an integrated coastal water resources management policy and a guideline framework is necessary and has an emergency state. The finding of this study could help to the policy and decision makers to prepare a guideline framework for a heritage management plan as well as for a general integrated coastal mangrove forest and wetland resources protection, conservation and management in Bangladesh.

Besides the above elements and factors the following important issues should be included in the national coastal mangrove forest and wetland resources management and conservation plan, which should be developed based on the changing tendency of ecosystems in the deltaic coastal region of Bangladesh. So the following recommendations could be considered in making the policy framework for better management in order to achieve the goal for a sustainable coastal mangrove forest and wetland water resources management:

- Increase coastal community socio-economic welfare and alleviate poverty for sustainable livelihood in the vulnerable coastal region. Provide alternative income generation opportunities to the coastal communities that should be ecologically friendly and profitable.
- Increase public awareness concerning environmental training and education, particularly related to the importance of the sustainable use of coastal mangrove forest and wetland and other natural resources. Provide information to the coastal communities concerning natural resources collection, proper uses and long-term protection measures.
- Coastal mangrove forests and wetlands biodiversity maintenance in the region; mangrove ecosystem functions and services should be included in the maintenance of the coastal region for a better interest of coastal communities in the Sundarbans Natural World Heritage Site of the Ganges-Brahmaputra Rivers deltaic mangrove forest and wetland region.
- To develop and train up capacity building of the local community groups, local government, stakeholders, NGOs and national policy makers and planners those are involved in coastal resource management activities in the Sundarbans Natural World Heritage Site or its surrounding Ganges-Brahmaputra deltaic coastal mangrove forest and wetland region in Bangladesh.

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