Environmental Sustainability (2018) 1:113–131
https://doi.org/10.1007/s42398-018-0018-y

REVIEW

Sundarbans mangrove forest of Bangladesh: causes of degradation and sustainable management options

S. M. Didar-Ul Islam[1] · Mohammad Amir Hossain Bhuiyan[2]

Received: 27 March 2018 / Revised: 8 July 2018 / Accepted: 10 July 2018 / Published online: 23 July 2018

Abstract
Sundarbans are highly productive mangrove wetland ecosystems, contributing several social, financial and environmental benefits. The forests have a great role in the countries national economy, and provides livelihood for the local people through fishing, tourism, wood and non-wood products. But despite several laws, policies and management plans, the forest is now showing clear signs of degradation. The aim of this study is to explore the major causes of degradation of Sundarbans mangrove forest in Bangladesh and to propose a management approach for its sustenance. It was found that, biodiversity and ecosystem of the Sundarbans is threatened due to several natural and human induced pressures, including overexploitation of forest resources, changes in coastal land use, pollution from industrial and agricultural sources, oil spillage, upstream water flow reduction, increased salinity level, disease outbreaks, fire occurrence, climate change, rise in sea level, natural disasters, lack of knowledge about forest conservation, uncontrolled tourism, inadequate planning and management, and increase in man–animal conflicts. In this background, an integrated approach is proposed, by refining the existing management and combining updated information through supplementary scientific studies and expeditions on mangrove forests. Proper implementation of the proposed resilient strategies i.e., incorporate all stakeholders to protect the forest, awareness programs, reduced forest dependency of local people, strengthen monitoring, ecological restoration, implementation of legal bindings, disaster management and adequate research and planning can be helpful for sustainable management of Sundarbans and similar mangrove forests around the world.

Keywords Biodiversity · Conservation · Environmental degradation · Forest ecosystem · Mangroves · Sustainability

Introduction

Mangroves are swamp forests, found in sheltered estuaries along with river banks and lagoons in the tropical and subtropical countries (Kumar et al. 2016; Malik et al. 2017). They are renowned for their floral and faunal diversity (Iftekhar and Takama 2008), with some particular adaptive capacities to the coastal environment i.e., coastal tides, salinity, siltation and sedimentation (Paul et al. 2017). Mangroves have great role in countries national economy by their natural productivity and variety of products and services, in the form of renewable resources (Aheto et al. 2016). The economic potential of mangroves depends on three key sources; forest products, fisheries, and ecotourism (Paul et al. 2017). Moreover, mangroves play a vital role in coastal protection and preservation of habitats of endangered species (Mukhtar and Hannan 2012; Sandilyan and Kathiresan 2014).

The global pattern of biodiversity in mangroves showed that, over 41% of the world's mangroves exist in South and Southeast Asia, where Indonesia alone occupied for 23% (Malik et al. 2017). A further 20% of the total mangrove areas lie in Australia, Brazil and Nigeria (Gopal and Chauhan 2006). However, the mangroves located in Ganges–Brahmaputra–Meghna (GBM) delta shared between Bangladesh and India are the largest mangrove forests in the world. It covers around 6017 km^2 area and represents a unique ecosystem being habitat for the endangered Royal Bengal Tiger (*Panthera tigris*) (Iftekhar and Saenger 2008). Considering the conservational value of the Sundarbans, in 1997 United Nations Educational, Scientific and Cultural

✉ S. M. Didar-Ul Islam
didar_577@yahoo.com

1 School of Environment, Tsinghua University, Beijing 100084, China

2 Department of Environmental Sciences, Jahangirnagar University, Dhaka 1342, Bangladesh

Organization (UNESCO) has declared 1397 km^2 forest area as the World Heritage site (WCMC 2001). Besides, south-west part of this forest (Ramsar site) is also declared as world's most important wetlands (Islam 2011). This forest is economically very significant to the marginal people of south-western Bangladesh, and is responsible for nearly 41% of the total forest revenue in Bangladesh (Roy and Hossain 2015). But, Sundarbans mangrove forests at one time covered nearly double the area, what exists at present (Das and Mandal 2016). In recent decades, mangroves have been increasingly threatened due to several human induced pressures i.e., changes of land use patterns, effluent discharges from industry and aquaculture ponds, decrease in freshwater flow, agricultural run-off, and oil spillage from sea ports; which have severe negative effects on biodiversity of Sundarbans (MacFarlane et al. 2007; Islam and Bhuiyan 2016; Chowdhury and Maiti 2016; Das and Mandal 2016). In addition, several diseases, natural disasters, rise in sea level and insufficient regeneration also affect the Sundarbans (Hossain et al. 2015). Degradation also occurred because of the development of Mongla export processing zone (EPZ) and sea ports in Khulna, for exports and imports (Hossain et al. 2015). The influence of anthropogenic pressure and contaminants from various sources may change the ecological stability of the mangroves in long run (Hossain and Bhuiyan 2016).

Owing to the concept of sustainable development and coastal environmental conservation in Southeast Asian countries, it is of great importance to understand the Sundarbans mangrove ecosystem, which is under threat due to natural and anthropogenic causes (Kumar and Ramanathan 2015; Neogi et al. 2016). To manage mangrove ecosystems sustainably within an integrated approach, it is essential to identify the information gaps and constraints. Although mangroves have been exploited for many centuries, the initiative for sustainable resources exploitation remained elusive. In these circumstances, this paper reviews the Sundarbans mangrove ecosystem, its services and role to the national economy of Bangladesh. This study also emphasizes to find out the causes of deteriorating Sundarbans mangrove, and finally propose an adequate future management guideline for sustainable forest management and conservation of this world heritage site.

Sundarbans mangrove and its role in national economy

The Sundarbans are the world's largest mangrove forests, situated between India–Bangladesh border. These are located at the northern shoreline of the Bay of Bengal and the Bangladesh part of the Sundarbans lies between 89°00′ and 89°55′E and 21°30′–22°30′N (Fig. 1). It is known as one of the most diverse and productive ecosystems in the world (Borrell et al. 2016). Apart from being a unique ecosystem, Sundarbans provide extensive protection to coastal populations from cyclones, tidal flooding, erosion and other natural disasters (Das and Vincent 2009; Payo

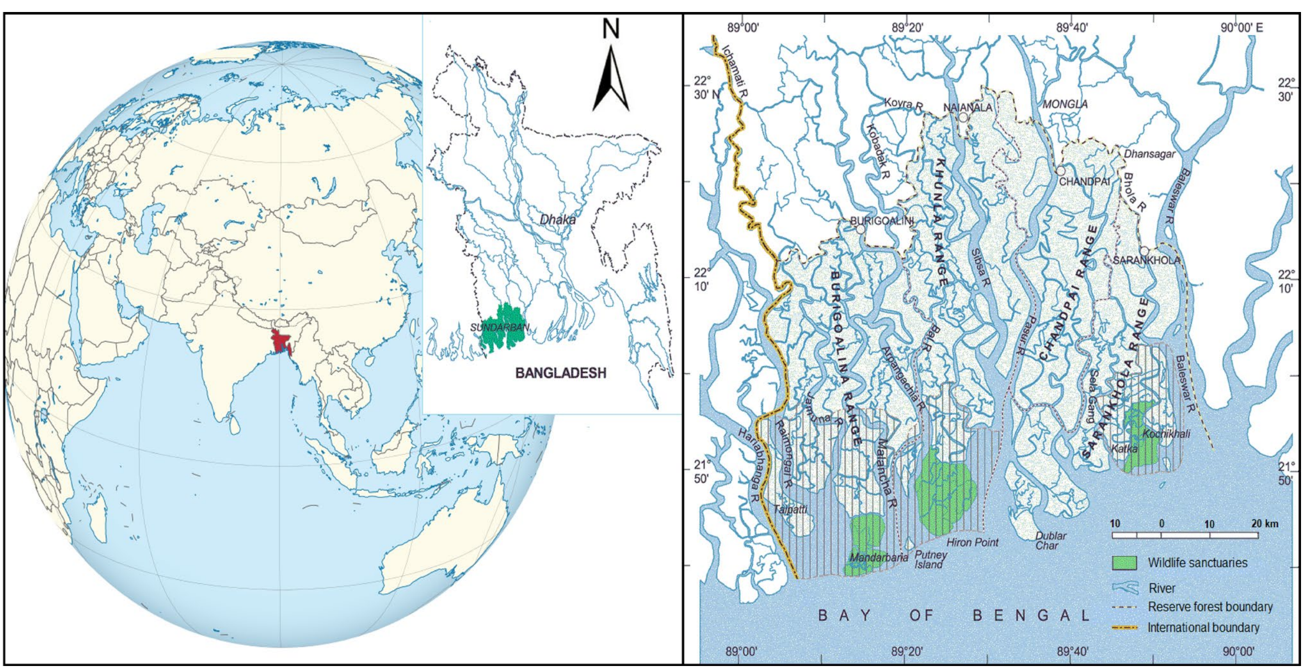

Fig. 1 Sundarbans mangrove forest in coastal zone of Bangladesh

et al. 2016). For example, in case of recent cyclones Sidr (November 17, 2007) and Aila (May 25, 2009), Sundarbans acted as a protective barrier for the coastal communities (Islam 2013; Bhowmik and Cabral 2013). This forest consists of 200 islands, detached by 400 inter connected tidal rivers and canals (Banglapedia 2010). According to the recent estimation, the area of the Sundarbans in Bangladesh is 599,330 ha; which contains about 62% (Rahman et al. 1979) and the rest of the area (426,300 ha) is in West Bengal province of India (Sanyal 1983). It is a habitat for diverse floral and faunal species. In Sundarbans, nearly 334 species of plant, 50 species of mangrove, 35 legumes, 29 grasses, 19 sedges, and 18 euphorbias were identified by Chaffey et al. (1995). Among them, most significant and economically important plants are; Sundari (*Heritiera fomes*), Goran (*Ceriops decandra*), Garjan (*Rhizophora mucronata*), Gewa (*Excoecaria agallocha*), Golpata (*Nypa fruticans*), Keora (*Sonneratia apetala*), Passur (*Xylocarpus mekongensis*), Baen (*Avicennia officinalis*), Chanda lota (*Dalbergia candenatensish*), Amur (*Amoora cucullata*), Dhundul (*Xylocarpus granatum*), and Nol-hash (*Eriochloa procera*). However, Sundari is considered as threatened, due to the occurrence of top dying disease (Rahman et al. 2003; Sarwar 2015). The Bhat Kati (*Bruguiera parviflora*) and Kala Baen (*Avicennia marina*) are also rare plants found in Sundarbans (MoEF 2010). In addition, Sundarbans are habitat for variety of faunal species. Bangladesh part of Sundarbans is known to have 45, 42, 46 and 36% mammals, birds, reptiles and amphibian species respectively, amongst the total wild life species of Sundarbans including West Bengal (India) part (Table 1). The Sundarbans is host to about 50 species of mammals, 320 species of birds, 53 species of reptiles, 11 species of amphibians, 177 species of fish and 873 species of invertebrates (Table 1). However, 10 species of mammals, 11 species of birds, 16 species of reptiles and 1 species of amphibians are identified as endangered in Sundarbans (Khan 2013). Some of the endangered species are Royal Bengal Tiger (*Panthera tigers*), Jungle cat (*Felis chaus*), Rock python (*Python molurus*), Estuarine crocodile (*Crocodilus porosus*), Irrawaddy dolphin (*Orcaella brevirostris*), Northern river terrapins (*Batagur baska*), King crabs (*Horse shoe*), and Green frog (*Euphlyctis hexadactylus*) (Sarker 1993).

Mangrove forests served various economic, social and environmental benefits. These forests provide livelihood for local people through fishing, honey and wax collection, tourism, wood and non-wood products (Islam and Islam 2011). Table 2 provides the information about shrimp, crab, honey, snails and bee wax production since the fiscal years 1999–2000 to 2012–2013 from Sundarbans. Sundarbans mangrove forest also meet the demand of wood for fuel, furniture, house posts, boats, bridges, construction and other things for household purpose. In 2003–2004 the estimated wood production by the Forest Department was 433,000 t (Hoq 2008). Table 3 provides the list of economically important trees and their uses, which have great role in national economy of Bangladesh. Former study showed that, only Sundari and Gewa trees of Sundarbans cover 40 and 21 m^3/ha/year, respectively, with monetary value equivalent to 125 and 23 US$/$m^3$ respectively (Uddin et al. 2013). The revenue income from forest is continuously increasing, due to increase in the tourists and visitors which enhanced by almost 25 times in 2012–2013 in comparison to 2000–2001

Table 1 Comparison of wildlife species in Bangladesh Sundarbans with West Bengal (India) and around the world. Sources: [a]Mandal (2003), [b]Anon (2010), [c]Rahman (2011), [d]IUCN (2003), [e]Khan (1986), [f]Khan (2013)

Taxonomic group	World's species[f]	Species in sub-continent[f]	West Bengal (India) Sundarbans[a]	Bangladesh Sundarbans
Protozoa	31,250	2577	106	175[b]
Porifera	4562	500	Invertebrates species 1104	Invertebrates 873[c]
Cnidaria	9916	842		
Ctenophora	100	12		
Rotifera	2500	330		
Gastrotricha	3000	100		
Platyhelminthes	17,500	1622		
Nematoda	30,000	2850		
Mollusca	66,535	5072		
Echinodermata	6000	765		
Arthopoda	987,949	68,389		Shrimps 24[d] Crabs7[d]
Fish	21,723	2546	481	177[c]
Amphibians	5150	248	–	8[e]/11[c]
Reptiles	5817	460	55	50[e]/53[a]
Birds	9026	1232	248	261[f]/320[a]
Mammals	4629	397	58	50[f]

Table 2 Products and services production from the Sundarbans since 1999–2000 to 2012–2013. Sources: Das (2013), Khan (2013), BFD, DoF (2014)

Financial year	Shrimp (no.)	Crab (t)	Honey (t)	Snails (t)	Bees wax (t)
1999–2000	–	–	555.20	6089.80	138.90
2000–2001	–	–	346.50	6007.90	86.60
2001–2002	3,436,940	364.20	234.10	3250.30	61.90
2002–2003	9,828,200	1384.0	279.60	774.60	64.20
2003–2004	54,900	2144.0	337.80	1531.00	84.44
2004–2005	–	2924.0	396.20	2362.90	98.92
2005–2006	–	2998.0	321.80	3230.30	80.00
2006–2007	–	2135.0	599.40	203.60	141.50
2007–2008	569,560	4014.84	374.00	134.60	93.51
2008–2009	1,175,020	3625.19	304.22	01.10	68.02
2009–2010	434,200	15,397.37	175.65	00.30	69.69
2010–2011	73,200	3106.93	361.50	1028.90	81.29
2011–2012	–	1301.56	165.45	1036.58	41.74
2012–2013	–	–	186.32	1032.21	40.25

Table 3 Economically important plant species of the Sundarbans and their uses. Sources: Rahman et al. (2010), Khan (2013), Aziz and Paul (2015)

Family	Scientific name	Type of plant	Main uses
Avicenniaceae	*Avicennia officinalis*	Tree	Fuel wood, anchor
Combretaceae	*Lumnitzera racemosa*	Small tree	Fuel wood, posts
Euphorbiaceae	*Excoecaria agallocha*	Tree	Matchsticks and raw material for newsprint
Leguminosae	*Cynometra ramiflora*	Small tree	Fuel wood, charcoal
Malvaceae	*Xylocarpus mekongensis*	Tree	Furniture, bridges, house
Meliaceae	*Xylocarpus granatum*	Small tree	Fuel wood
Palmae	*Nypa fruticans*	Recumbent Palm with underground stem	Thatching for houses
Rhizophoraceae	*Phoenix paludosa*	Thorny palm	Post and rafters for huts
Rhizophoraceae	*Bruguiera spp.*	Tree	Furniture, bridge and house construction
Rhizophoraceae	*Ceriops decandra*	Shrub or small tree	Fuel wood, house posts, charcoal
Arecaceae	*Nypa fruticans*	Palm	Hose construction, biofuel, medicinal use
Sonneratiaceae	*Sonneratia apetala*	Tree	Packing boxes, paneling
Sterculiaceae	*Heritiera fomes*	Tree	House construction, hard boards

(Fig. 2a, b). Total revenue income from the forest products of Sundarbans are mentioned in Table 4. The increase of revenue collection from US$ 717,409 in 2008–2009 to US$ 879,181 in 2012–2013 fiscal year is shown.

Causes of degradation of Sundarbans mangrove ecosystem

Sundarbans mangrove forest is one of the most threatened wildlife habitats over the globe. The increasing trend of human population and their forest dependent livelihood is the main reason for mangrove degradation (FAO 2004; Ali et al. 2006). Besides overexploitation, carelessness of restocking, land reclamation, pollution, fishing and shrimp farming activities also create serious threats (Chowdhury and Maiti 2016). It has been witnessed that, 5% of forest cover was decreased within the period of 1989 and 2010 (Mahadevia and Vikas 2012). However, the major causes of the degradation of Sundarbans mangrove are described in the following sections.

Over exploitation and illegal forest cutting

To meet the rising demand of people, Sundarbans are facing over exploitation. Encroachment and illegal cutting of timber and firewood are the major problems (Paul et al. 2017). The main reasons of illegal forest cutting are; wide demand of wood, and unemployment in nearby areas. Sundarbans are situated near the Khulna news paper mill, which relies on

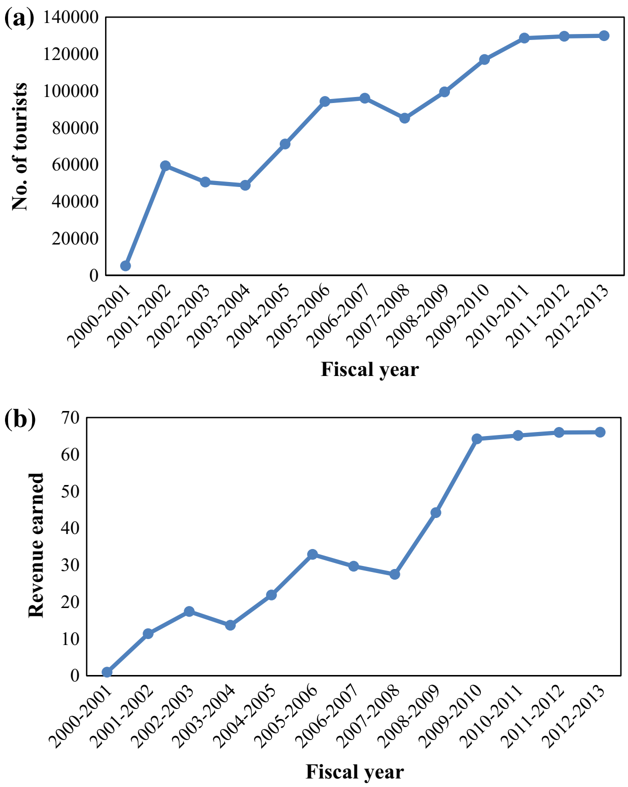

Fig. 2 **a** Number of tourists visited in Sundarbans, and **b** the revenue income (lac in BDT), since 2000–2001 to 2012–2013. Sources: DoF (2014) and Roy and Hossain (2015)

nearby legal timber supplies (Rahman et al. 2010). Although, local people collected timber and fuel wood, animal fodder, medicines, fish, crabs, and honey for centuries, but recently significant exploitation occurred due to the increase of population pressure on Sundarbans (Rahman et al. 2010). Table 5 illustrates the scenario of forest cover change between 1989 and 2015, analyzed by remote sensing images. Due to illegal encroachment, biodiversity of Sundarbans is quickly disappearing. Table 6 shows the rare, threatened and endangered floral species; and Table 7 shows the threatened and extinct faunal species of Sundarbans. Moreover, fishing and collecting non-timber wood is the main livelihood for local people, which put the mangrove environment under incredible pressure. It has been also reported that, the density of fishes in shallow waters has declined (Mahadevia and Vikas 2012). Further, due to excessive collection of shrimp seed and artificial culture in forest areas, mangrove ecosystem is severely threatened (Islam and Bhuiyan 2016).

Change in coastal agricultural patterns and land use

Due to rapid population growth, present agriculture production is insufficient to meet the demand of the surrounding areas of Sundarbans. The main economic activity of the local people is to cultivate salinity tolerant rice species (Hussain 2013; Islam et al. 2016). Besides, rapidly expanding shrimp farming and salt production (evaporation of seawater to produce salt) take part in deterioration of the mangroves of Bangladesh (Islam and Bhuiyan 2016; Abdullah et al. 2017). The land cover of shrimp farm has increased from 22,000 to 276,000 ha between 1980 and 2013 (Islam and Bhuiyan 2016). Mangrove swamps are used for fishing, and shrimp farming mainly giant tiger prawn (*Penaeus*

Table 4 Forest products and revenue earned during 2008–2009 and 2012–2013 from the Bangladesh part of Sundarbans. Sources: Aziz (2013), Department of Forest (2014), Aziz and Paul (2015)

Type of forest	2008–2009		2012–2013	
Produces (unit)	Amount	Revenue (BDT)	Amount	Revenue (BDT)
Excoecaria agallocha (1/m^3)	613	779,626	252	1,254,319
Ceriops decandra (no.)	88,708	363,628	66,578	379,290
Nypa fruticans (t)	37,534	4,620,713	31,761.6	8,275,050
Fishes (t)	4524.5	21,331,210	3484.5	13,569,648
Grass (t)	493	10,853	1101	29,837
Phoenix paludosa (t)	60	42,846	73.02	105,899
Honey (t)	110	608,520	233	1,747,422
Mollusk shell (t)	1349	40,987	182.714	32,888
Wax (t)	22.81	228,195	58.93	589,315
Crab (t)	1318.5	3,743,765	1253.80	4,901,712
Tourists (no.)	183,600	4,419,960	150,037	19,873,725
Wood (1/m^3)	522.60	8,452,509	293	2,220,170
Fuel wood (1/m^3)	850	557,209	453	8,39,173
Miscellaneous	–	10,040,444	–	13,878,556
Total	–	48,202,163 or US$ 717,409	–	67,697,004 or US$ 879,181

Table 5 Changes of vegetation density and health of Sundarbans since 1989–2015, determined by remote sensing image. Source: Paul et al. (2017)

Category	Vegetation density		Vegetation health	
	Area (m^2) in 1989	Area (m^2) in 2015	Area (m^2) in 1989	Area (m^2) in 2015
Very low	50,230	31,208	3944	7702
Low	85,561	86,190	14,309	22,232
Moderate	102,721	105,166	34,950	46,793
High	108,554	106,901	77,392	79,385
Very high	110,336	107,964	106,895	101,229

Table 6 Rare, threatened and endangered floral species of Sundarbans mangrove forest. Sources: Gopal and Chauhan (2006), Khan (2013), Aziz and Paul (2015)

Family	Species	Status
Rhizophoraceae	1. *Rhizophora apiculata*	Occasional
	2. *Bruguiera parvifl ora*	Occasional
	3. *Ceriops decandra*	Occasional
	4. *Kandelia candel*	Occasional
Meliaceae	5. *Aglaia cucullata*	Rare
	6. *Xylocarpus mekongensis*	Threatened
	7. *Xylocarpus granatum*	Threatened
Sterculiaceae	8. *Heritiera fomes*	Threatened
Rubiaceae	9. *Scyphiphora hydrphyllacea*	Very rare
	10. *Hydrophyllax maritime*	Very rare
Tiliaceae	11. *Brownlowia lanceolata*	Occasional
Arecaceae	12. *Nypa fruticans*	Occasional
Acanthaceae	13. *Acanthus volubilis*	Very rare
Papilionaceae	14. *Cynometra ramifl ora*	Rare
	15. *Dalbergia spinosa*	Rare
Sapotaceae	16. *Manilkara hexandra*	Rare
Rutaceae	17. *Atalantia correa*	Very rare

monodon) farming (Rahman et al. 2010). For example, the Chokoria Sundarban at the eastern coast of Bay of Bengal has completely been destroyed because of shrimp farming (Iftekhar and Islam 2004; Rahman and Hossain 2015). There are 14 different fishing methods and ghers (shrimp farming ponds) used by the fisherman inside the Sundarbans (Islam and Bhuiyan 2016). Immense clearance of mangroves is taking place to build shrimp culture ponds, which also results in reduction of the mangrove habitat (Islam and Bhuiyan 2016). Shrimp farms are extensively grown-up at the south-western coastal region of Bangladesh. Huge amounts of agrochemicals and hormones are used in shrimp farms to control the disease and pests (Hossain et al. 2013; Islam and Bhuiyan 2016), which ultimately degrade the coastal ecosystems. Moreover, about 4520 t of pesticides are being used for agricultural activities in the coastal districts of Bangladesh (Rahman et al. 2009). Among them, almost 25% (1130 t) of pesticides residue may go to the nearby water bodies (FRI 1994; Rahman et al. 2009). This indiscriminate and excessive use of pesticides poses great threat for aquatic environment of mangroves, and contaminate the food chain.

Coastal pollution

To improve the living standards in coastal areas, recently various industrial activities have come up along with aquaculture farming which discharged huge amount of garbage, wastewater and others effluents (Rahman et al. 2010). Increased movement of tourist ships and boats causes noise pollution and wastes released from them also degrade the wild environment (Hussain and Acharya 1994). Sundarbans mangrove ecosystem also became vulnerable due to pollution by different trace elements and agrochemical residues, which may change the biogeochemistry of mangroves (Rahman et al. 2009). Pesticides and high concentration of trace elements e.g., Cd, Cr, Cu, Pb, and Zn were identified in mangrove sediments (Chowdhury and Maiti 2016; Kumar et al. 2016). Table 8 shows the trace metals concentrations of Sundarbans, compared with other mangroves in the world. It was found that, toxic Zn accumulation capacity of shrimp is much higher, in comparison to other fish species (Ghosal et al. 1997). Ahmed and Ali (2004) found that trace metal concentration in some benthic animals e.g., hermit, king crab, mudskipper, and gastropod exceeds the tolerant limit in Pasur river of Sundarbans. Table 9 describes the concentrations of trace elements uptake by some species of Sundarbans. Due to excessive trace metal contamination, mangrove plants may initiate a variety of sub-cellular responses, which can change the cellular structure (Arora et al. 2010). Rahman et al. (2009) reported high concentration of trace elements in mangroves is changing the physiology of species, causing death of plants and animals, contaminating the food chain and rising the risk to future re-generations.

Oil spillage

Contamination by oil spillage is a severe threat for mangroves, and harmful for aquatic species and sea birds. Sources of oil pollution are potentially due to the Mongla sea port situated just 3 km away from the Sundarbans. This port annually deals with approximately 1500–1600 vessels and 12,000–13,000 cargo ships (Rahman et al. 2009). Frequently, shipping vessels pass through the Sundarbans using north-east route (Scott 1989). Many mechanized river crafts and fishing boats also enter the Sundarbans

Table 7 Threatened and extinct fauna of Sundarbans mangrove forest. Sources: Asmat (2001), Gopal and Chauhan (2006), Khan (2013), Rahman (2014)

Threatened fauna		Extinct fauna	
Common name	Scientific name	Common name	Scientific name
Mammals			
Barking Deer	*Muntjanus muntjack*	Striped Hyena	*Hyaena hyaena*
Royal Bengal Tiger	*Panthera tigris tigris*	Malayan sun Bear	*Helorctos malayanus*
Leopard Cat	*Felis bengalensis*	Smaller One Horned Rhinoceros	*Rhinoceros sondaicus*
Fishing Cat	*Felis viverrina*	Asiatic Gaur	*Bos frontalis*
Gangetic Dolphin	*Platinista gangetica*	Wild Buffalo	*Bubalus bubalis*
Irrawady Dolphin	*Orcaela brevirostris*	Bulebull	*Bocehpalus tragocamelus*
Little Indian Porpoise	*Neophocaena phocaenoides*	Pygmy Hog	*Sus salvinus*
Chinese Pangolin	*Manis pentadactyla*	Wolf	*Canis lupus*
		Great one Horned Rhinoceros	*Rhinoceros unicornis*
		Two Horned Rhinoceros	*Dicerohinus sumatrensis*
		Banteng	*Bos javanicus*
		Black buck	*Antelope cervicapra*
		Swamp Deer	*Cervus duvauceli*
Reptiles			
Estuarine Crocodile	*Crocodylus porosus*	Indian Egg Eating Snake	*Elachistodon westermanni*
Olive Ridley Turtle	*Lepidochelys olivacea*	Mud Turtle	*Trionyx nigricans*
Batagur Turtle	*Batagur baska*		
Indian Flapshelled Turtle	*Lissemys punctata*		
Indian Softshelled Turtle	*Trionyx gangeticus*		
Indian Tent Turtle	*Kachuga tecta*		
Yellow Monitor	*Varanus flavescens*		
Water Monitor	*Varanus salvator*		
Indian Rock Python	*Python morulus*		
Aves/birds			
Great Goliath Heron	*Ardea goliath*	Bengal Pinkheaded Dock	*Rhodonessa caryophyllacea*
Dalmatian Pelican	*Pelecanus phillippensis*	Bengal Florican	*Eupodotis bengalensis*
Lesser Adjutant Stork	*Leptotilos duius*	Painted Stork	*Mycteria leucocephala*
		King Vulture	*Sarcogyps calvus*
		Indian Peafowl	*Pavo cristatus*
		Green Peafowl	*Pavo muticus spicifer*
		Greater Adjutant	*Leptoptilos dubius*

frequently. These vessels discharge waste oil and cause oil spillages, and release others wastes (UNEP 2001). Crude oil and its byproducts also create serious contamination, during the shipment through the rivers of Sundarbans (Rahman et al. 2010). Rahman et al. (2009) gave an estimation about the crude oil spills in Bay of Bengal, and it is reported to be around 400,000 t per year, where the contribution of Bangladesh is nearly 6000 t. Bangladesh imports approximately 1.20 and 0.5 million tons of crude oil and refined oil annually, which is shipped via small tankers (PMA 2005). Contamination mainly occurred from these vessels and sometimes from accidental spillages. There are many examples of such accidental spillage. Since 1990, huge oil spill was noticed in Chandpai Range of Sundarbans from unknown source. Again, near the Dhangmari forest station an oil spill occurred in 1994 due to ship wreckage, which spread almost 15 km (Rahman et al. 2009). Recently (in 2014), a vast oil spill occurred at the Shela River in Sundarbans. The spill occurred when an oil-tanker carrying 350,000 l of furnace oil, collided with a cargo vessel and sank in the river and the oil spread over 350 km^2 area (The Daily Star 2014; SOSA 2014). Such spills threatened trees, plankton, small fish, dolphins and birds. The water soluble fractions of oils like; benzene (C_6H_6), toluene ($C_6H_5CH_3$), and phenols (C_6H_5OH) are very toxic to floral and faunal species of Sundarbans (Rahman et al. 2010). Shigenaka (2002) found that, aromatic hydrocarbons having lower molecular weight are the main components of oil mixtures, which can damage the cellular membranes of mangrove roots. Moreover, oil attached on the leaf surface can block stomata and affect photosynthesis, respiration, and metabolism of the mangrove plants (Rahman et al. 2010).

Table 8 Comparison of trace elements concentrations (μg/g) in surface sediment of Sundarbans with mangrove sediments around the world. Sources: [a]Kumar et al. (2016), [b]Ranjan et al. (2008), [c]Ray et al. (2006), [d]Singh et al. (2005), [e]Janaki-Raman et al. (2007), [f]Guzmán and Jiménez (1992), [g]Perdomo et al. (1999), [h]MacFarlane et al. (2003), [i]Preda and Cox (2002), [j]Harris and Santos (2000), [k]Machado et al. (2002), [l]Tam and Wong (2000), [m]Ong Che (1999)

Locations	Cd	Cr	Ni	Cu	Zn	Pb	Fe	Mn	As	Co
Sundarbans[a]	0.09	52.87	207.31	44.69	74.09	25.61	42,172.17	740.95	19.80	17.56
Pichavaram[b]	34.74	617.00	252.10	132.30	106.00	143.80	24,998.00	801.00	–	–
Godavari[c]	10.90	2.20	25.70	47.80	–	55.80	4575.00	1059.00	–	–
Goa[d]	–	–	52.00	26.00	–	–	–	767.00	–	–
Muthupet[e]	0.24	141.20	62.00	32.00	89.00	11.20	32,482.00	701.00	–	–
Panama										
PuntaMala Bay[f]	< 10	23.30	27.30	56.30	105.00	78.20	9827.00	295.00	–	–
Toro Point[f]	6.60	13.70	82.40	4.90	199.90	38.00	1885.00	294.00	–	–
Galeta[f]	7.20	12.80	74.00	4.00	10.90	32.50	1748.00	143.00	–	–
Payardi[f]	7.50	10.00	91.80	4.00	16.10	33.30	2094.00	228.00	–	–
Costa Rica										
Punta Portete[f]	7.30	22.60	102.00	8.40	14.70	34.50	3225.00	268.00	–	–
Punta Piuta[f]	6.00	19.80	99.00	9.80	11.40	25.60	6118.00	525.00	–	–
Colombia										
Cienaga Grande[g]	1.92	13.20	32.50	23.30	91.00	12.60	15,593.00	623.00	0.059	–
Australia										
Port Jackson[h]	–	–	–	62.00	145.00	180.00	–	–	–	–
Hawksbury[h]	–	–	–	18.90	94.00	26.40	–	–	–	–
Queensland[i]	0.60	1–72	9.00	1–12	23–56	36.00	1056.00	103.00	–	–
Brazil										
Clean Mangrove[j]	0.60	–	–	3.82	24.20	–	2464.00	–	–	–
Guapimiri Mangrove[k]	–	–	12.00	28.30	26.70	26.00	–	–	–	–
Sao Goncalo Mangrove[k]	–	–	8.70	18.0	610.00	20.00	–	–	–	–
Ilha do Governador Mangrove[k]	–	–	6.00	80.00	263.00	130.00	–	–	–	–
Duque de Caxias Mangrove[k]	–	–	10.30	46.70	53.30	86.70	–	–	–	–
Hong Kong										
Clean mangrove[l]	1.08	2.90	31.20	43.00	96.00	2.60	1.20	–	–	–
Mai Po[m]	0.60	14.00	66.00	46.00	293	199	423	–	–	–

Upstream water flow reduction and salinity

Stream flow of Ganges, Bahmaputra and Meghna (GBM) rivers are the sources of freshwater in Bangladesh (Rahman et al. 2016; Bhuiyan et al. 2017). Sundarbans mangrove forests receive freshwater discharge mainly from the flow of Ganges River (Rahman and Rahman 2017). Annual peak discharge of the river varies from 31,600 to 76,000 m^3/s and minimum discharges were found to be 657–858 m^3/s near the Hardinge Bridge, located about 185 km upstream of Sundarbans (Aziz and Paul 2015). The Gorai River originates from the Ganges and the freshwater carried by it is distributed to Passur (85%) and Baleswar (15%) rivers. But the pattern has changed since 1975, due to the diversion of water at Farakka Barage in India, just 17 km upstream from Bangladesh (Mirza 1998). It has been found that, since the period of 1997–2015, the maximum, average and minimum discharges have reduced by almost 23, 43 and 65%, respectively, in dry season (January–May), comparing to the pre-barrage period i.e., 1935–1975 (Rahman and Rahman 2017). The Sundarbans ecosystem depends on the availability of fresh water. But, due to reduction of water flow from upstream, salinity rate increased from 10 to 25 dS/m in between 1968 and 2003 (Islam and Gnauck 2009). As a result, the regeneration of Sundari, the dominant timber species of Sundarbans has reduced in the south-western part (Paul et al. 2017), which are the high salinity affected areas of Sundarbans (Fig. 3). Salinity is an important physiological factor, used as one of the influencing parameters to assess the potential for plant species and brackish water animals (Nandy et al. 2007). Optimum level of salinity is essential for plant growth (Clifford 1985). Balanced water flow maintains the optimum environmental and ecological conditions for mangroves development. But due to fresh water withdrawal from the Ganges River in upstream, coastal mangrove ecosystem is now severely threatened (Rahman et al. 2016,

Table 9 Concentrations (mg/kg dry weight) of trace elements uptake by some species of Sundarbans

Locations	Species	Trace Elements							References
		Zn	Cu	Cr	As	Pb	Hg	Cd	
Indian Sundarbans (4 stations)	*P. monodon*	16–80	10–60	–	–	5.5–10	–	0–2.5	Mitra et al. (2012)
Indian Sundarbans (5 stations)	*P. monodon*	7–4810	–	–	–	7–25	–	0.01–0.54	Guhathakurta and Kaviraj (2000)
Bay of Bengal (Bangladesh	*P. monodon*	24–35	12–21	1.7–2.9	–	0.8–1.3	–	0.2–0.3	Hossain and Kahn (2001)
Bangladesh Sundarbans	*P. monodon*	48–55	18–25	1.6–5.4	0.3–0.4	0.02–0.06	0.08–0.11	0.003–0.008	Borrell et al. (2016)
Bangladesh Sundarbans	*S. serrata*	85.5	6.28	–	–	6.77	–	0.55	Ahmed et al. (2011)
Bangladesh Sundarbans	*S. serrata*	155–207	36–84	1.7–2.4	4–18	0.05–0.15	0.08–0.26	0.06–0.3	Borrell et al. (2016)
Indian Sundarbans	*H. nehereus*	11–16	nd–5	–	0.07–1.96	–	0.3–2.57	0.17–1.96	Kumar et al. (2012)
Indian Sundarbans	*H. nehereus*	–	–	–	20.62	–	–	–	Fattorini et al. (2013)
Bay of Bengal Bangladesh	*H. nehereus*	34	35	–	–	2.2	–	0.009	Sharif et al. (1991)
Bangladesh Sundarbans	*H. nehereus*	29–44	2–4	3.2–4.8	2–3	0.2–0.3	0.03–0.06	0.18–0.28	Borrell et al. (2016)
Indian Sundarbans (4 stations	*T. ilisha*	16–76	15–63	–	–	7–11	–	nd–1.35	Mitra et al. (2012)
Bangladesh Sundarbans	*T. ilisha*	8–10	1–4	1.2–2.4	3–7	0.02–0.1	0.01–.03	0.003–0.009	Borrell et al. (2016)
Indian Sundarbans (Hoogly)	*P. argentius*	11–34	10–23	–	–	3.8–21	–	0.55–1.28	De et al. (2010)
Indian Sundarbans	*P. argentius*	5–99	nd–28	–	nd–1.74	–	0.22–0.60	0–2.1	Kumar et al. (2012)
Bangladesh Sundarbans	*P. argentius*	12–18	0.5–1.2	2.2–4.4	2–6	0.01–0.1	0.03–.09	0.003–0.055	Borrell et al. (2016)

nd not detected

2017). It effects on the river morphology, groundwater, salinity, fisheries, forestry, ecology and navigation (Rahman and Rahman 2017). As a result, the major environmental agents are affected which are illustrated in Fig. 4.

Plant diseases

"Top dying" is one of the main causes for deteriorating dominant Sundari trees of Sundarbans (Sarwar 2015). Almost 5–6% of the total *H. fomes* across the Sundarbans is now suffering from this disease and half of them have been affected in high saline zones (Rahman et al. 2010). According to the Forest Department, "top dying" disease break outs occurred at large scale since 1980. Former study also indicates about 70% steams of *H. fomes* are affected moderately or severely by "top dying" disease (Islam and Wahab 2005). In 1994–1996, Forest Department survey results found that, average 134,291.70 m^3 of *H. fomes* died every year due to this disease and thus posing a significant loss in terms of biodiversity and economy. Besides, increasing salinity levels in Sundarbans are another significant threats to the trees. However, several diseases i.e., leaf blight (*Alternaria alternate, Botrydiploida theobromae, Gliocladium versoeseni*), leaf spot (*Cercospora rhizosphorae*), dieback (*Phytophthora nicotianae*), seed rot (*Fusarium* spp.), stump and collar rot (*Fomes* spp.), anthracnose (*Glomerella cingulata*), lethal yellowing (Mycoposma like bodies), bleeding disease (*Ceratocystis ulmi*), and powdery mildew (*Oidium* spp.) are also responsible for decline in the plant species of Sundarbans (Rahman et al. 2010).

Climate change and natural disasters

Climate change has serious impacts on coastal environment and livelihood, which threaten to damage mangroves (Dasgupta et al. 2017). UNESCO (2007) predicted that, due to anthropogenic stress and increase of 45 cm [Intergovernmental Panel on Climate Change (IPCC) predicts likely to happen at the end of the twenty-first century] in sea level, 75% of the Sundarbans forest will be destroyed. Natural resources of the Sundarbans, especially various plant species, are now in threatened condition due to sea level rise. It is predicted that, rising sea levels may already have flooded about 7500 ha areas of Sundarbans (WWF 2007). Stable sea levels are needed for long-term existence of mangroves. But, due to the global climate change rise in sea level and increased intensity and frequency of cyclones, storms, coastal floods and erosion (Islam and Uddin 2015), are disrupting the mangroves ecosystem (Neogi et al. 2016). Recent cyclones Sidr, Reshmi and Aila had devastating impacts on Sundarbans as reported by many authors (Islam 2013; Islam et al.

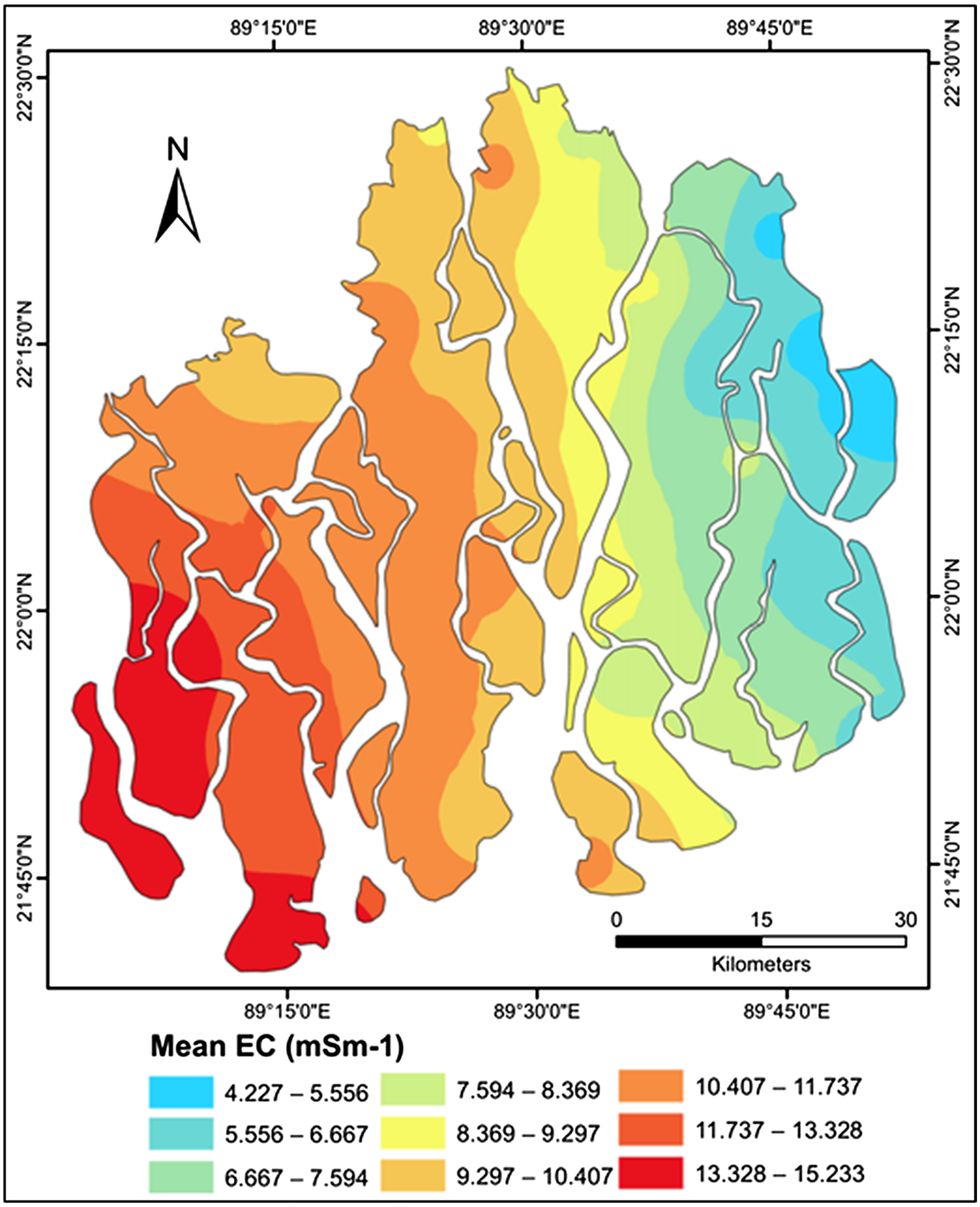

Fig. 3 Distribution of salinity in Sundarbans mangrove. Source: Hossain and Bhuiyan (2016)

2015; Dutta et al. 2015; Deb and Ferreira 2017). It was estimated that, the monetary value of the damage caused by cyclone Sidr is $142.9 million (Saadi 2010). Prolonged inundation by saline water flooding during cyclone devastated the mangroves (Paul et al. 2017). Furthermore, sediment deposition due to flooding causes harm to mangrove root system and regeneration (Deb and Ferreira 2017). Coastal erosion has also significant effects on the mangrove swamps (Pahlowan and Hossain 2015). Moreover, increase in CO_2 and ocean acidity changes the marine biogeochemistry which has long term effects on coastal mangrove ecosystem, by reducing the pH of water and soil (Vivekanandan et al. 2016).

Occurrence of fires

Fire is the major threat and recently caused serious damage to the Sundarbans mangrove. Forests in an area around 1.0 km^2 at Napitkhali under Chandpai range of Sundarbans got burnt, posing a threat to natural habitat for many rare species including the Royal Bengal Tiger (Rahman et al. 2010). In March 10, 2010 about 250 ha forest land was destroyed by fire; it was the habitat for many rare plants and animals. In the last 3 years, at least 12 fire incidents occurred in different parts of Sundarbans (MAP 2010). Sundarbans host various plant species which produce plenty of nectar collected by honey bees. Though mangroves are the key

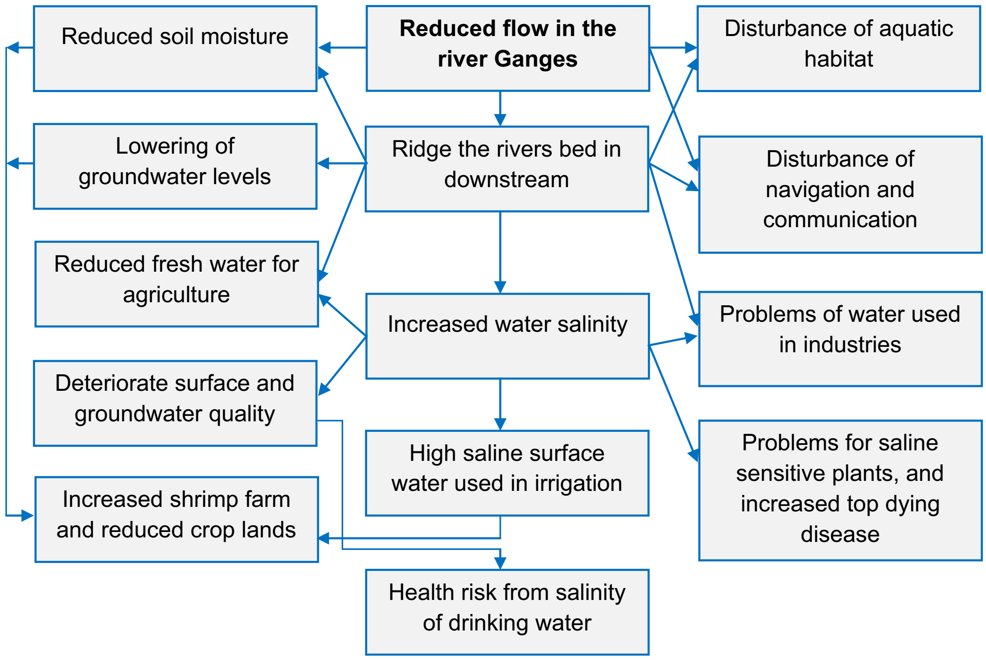

Fig. 4 Impacts of fresh water flow reduction on coastal environment

source of honey and wax in Bangladesh, but the collection practice is very traditional (Islam and Wahab 2005). Generally, honey collectors (mowal) use fire to remove the honey bees from nest, which sometimes spreads in Sundarbans due to lack of proper safety measures (Rahman et al. 2010).

Inadequate knowledge and high dependency of local people

The local people of Satkhira, Bagerhat and Khulna districts are highly dependent on Sundarbans for their livelihoods. These people are not well educated and have inadequate knowledge regarding the values of mangroves protection. They have lack of knowledge about forest conservation, thus destroy the forests resources (Rahman et al. 2010), although, numerous laws, regulations and policies exist for the protection of Sundarban mangroves. Moreover, global climate change affects the development of mangroves (Islam et al. 2015). So, appropriate measures should be taken immediately to ease the effects of climate change. However, despite the protection measures, there have been large scale human encroachments into the Sundarbans turning forest land to agricultural land. Such anthropogenic activities have put tremendous pressure on the Sundarbans.

Tourism

Tourism sector has developed successfully in Sundarbans, with the increase of visitors from 50,000 to 117,000 from the years 2002 to 2010 (Khanom and Buckley 2015). The main attraction for tourists of Sundarbans are Royal Bengal Tiger and spotted deer. Although tourism has significant role in local and national economy of Bangladesh, but it has detrimental effects on Sundarbans because of habitat destruction, noise pollution, poor sanitation, waste disposal and contamination (Khanom et al. 2011). Due to lack of ecotourism and proper monitoring, Sundarbans ecosystem is affected day by day (Das and Bandyopadhyay 2013).

Poor planning and management

Rahman et al. (2010) identified three basic reasons for disappearing mangrove forest in Bangladesh; (i) lack of well-trained forest security and officials, and institutional capacity (ii) lack of proper planning and sufficient knowledge about coastal zone management, and (iii) lack of application of the development plans. Recently examples of poor planning are the decision to establish 1320 MW coal fired power plant in Rampal, just 14 km away from the Sundarbans violating the rules of project implementation in eco-sensitive zone (Kumar 2013). Annually this plant will burn about 4.75 million tons of coal and generate roughly 0.3 and 0.5 million ton's ashes and other wastes respectively, including harmful effluents. It is also predicted that, from the coal burning huge amount of CO_2, CO, SOx, NOx, hydrocarbons, volatile organic compounds (VOC) and some other airborne particles will be emitted (The Daily New Age 2016). From experiences, it is known that, a typical coal based power plant uses only 33–35% coal heat to generate electricity (Chowdhury 2012). Major portion of this heat is absorbed by cooling water, which may discharge into the nearby Poshur River (Hance 2016). Furthermore, the source of bituminous coal is from West Bengal, India, using the channel and rivers of Sundarbans, which may hamper the sound environment of the forest and increase the threat.

Increased man–animal conflict

Due to global climate change, recent devastating cyclones and increased deforestation; wildlife habitat is badly affected. Moreover, huge forest land is lost due to submersion in water, which increase the threat of wild animals coming into human localities for food and shelter (Rahman et al. 2010). A conflict situation is increasing by the day among man and wild animals, which is harmful for both. This is particularly threatening for the existence of critically endangered Royal Bengal Tigers in Sundarbans region, that are historically known to prey on humans. In fact, it is well known that several tigers that entered into human habitations have been killed due to fear of man eating (Rahman et al. 2010).

Existing management scenarios of Sundarbans

The history of the Sundarbans mangrove management is very conventional. To manage Sundarbans mangrove, detailed work plan was first prepared in the year 1893–1894 (Chowdhury and Ahmed 1994). After that, a working plan was prepared to manage the forests based on the inventory of Sundarbans in period of 1960–1980 (Choudhury 1997). In 1993, forest master plan was prepared, which recommended two sanctuaries. In first sanctuary, yearly plantation target of around 18,000 ha areas during 1993–2002, and increase up to 21,000 ha during 2003–2012 was planned (MoEF 1993). But, due to financial and legal constraints planted trees could not be protected from grazing, illegal removal and encroachment (GoB 1993). Besides, the negligence and dishonesty of the personnel of forest department and local political leaders this initiative almost failed (Akhtaruzzaman 2000). The second one paid attention to the development of wildlife sanctuaries; and Sundarbans was divided into three divisions and declared wildlife sanctuaries. However, the areas of these sanctuaries are not sufficient to provide protection to wildlife in the long run (Islam and Wahab 2005; Rahman et al. 2010). Recently, a management plan for the protection of Sundarbans is being prepared by Food and Agricultural Organizations (FAO). The aim of this project is to achieve sustainable management of mangroves in order to utilize forest resources (Choudhury 1997). In recent times, forest cover, species diversity and ecosystem function have declined rapidly, although a number of guidelines (Table 10) exist to protect the forest resources. The main cause is the ineffectiveness of the plans and policies, due to lack of implementation capacity (Iftekhar and Islam 2004). Although, Department of Forest (DoF) tried to implement certain conservation plans i.e., national conservation strategy, environmental policy, and national environmental management plan to protect the Sundarbans. However, management approaches based on logical and scientific basis have not been developed yet (Rahman et al. 2010; Roya and Gowb 2015). Moreover, to find out sustainable and effective forest management plan, sufficient research efforts have not so far been under taken (Islam and Wahab 2005).

Sustainable forest management approach

Sustainable forest management depends on numerous factors i.e., integrated management of forest products and goods, active participation of key stakeholders, adequate planning and management, and effective monitoring (Uta et al. 1999). Conservation of forest ecosystems at local levels strengthen resource allocation, which also contribute to regional and global scale conservation (Aheto et al. 2016). Sundarbans mangrove forest in Bangladesh is now extensively degraded and poorly stocked. At this crucial moment it is now essential to develop and implement a sustainable forest management approach for survival of this unique ecosystem. To protect and conserve the Sundarbans mangrove forest of Bangladesh, following integrated approaches are proposed (Fig. 5).

i. Participation of key stakeholders: It involves local communities, forest officials, governmental agencies, researchers, national and international experts and organizations, donor agencies, policy makers, and participation and empowerment of women groups. Local people are the main and key stakeholders (Aheto et al. 2016), so they should be included in forest management plan.
ii. Public awareness and campaign: Public awareness about the values of forests and forest protection can be build up by seminars, workshops, training, meetings, videos and slide shows. Besides, publications (e.g., book, magazine, journal) on the value of mangrove forests can be helpful.
iii. Reduction of forest dependency: Most of the local residents are dependent on the forest resources for their livelihood. Due to rapid population growth and over exploitation, forest ecosystem is degrading. So, regional planning and relocation of people, set up of alternative livelihood, initiation of technical educa-

Table 10 Relevant policies, laws, rules, acts and treaties of Sundarbans mangroves forest. Sources: Alam (2002), Iftekhar and Islam (2004), DoF (2014)

Rules and regulations	Key concerns related to Sundarbans
Policy	
Forest Policy, 1994	Multiple use, sustained management, keep bio-environment intact
National Environment Policy, 1992	Environmental protection
National Water Policy, 1999	Environmental protection
National Industrial Policy, 1991	Forest product utilization
National Land use Policy, 2001	Land protection and management
National Coastal Zone Policy, 2004	Conservation of critical ecosystem, sustainable management, integrated planning
Rules and acts	
The Forest Act, 1927	Forest area/coverage, forest product extraction
The Marine Fisheries Ordinance, 1983	Fish and aquatic species diversity and characteristics
The Marine Fisheries Rules, 1983	
The Private Fisheries Protection Act, 1889	
The Protection and Conservation of Fish Act, 1950	
The Protection and Conservation of Fish Rules, 1985	
Bangladesh Wild Life (Preservation) Order, 1973	To protect faunal diversity
Brick Burning (Control) Act, 1989	Control pollution load, and to protect forest area/coverage
Coast Guard Act, 1994	
The Bangladesh Environment Conservation Act, 1995	
The Mongla Port Authority Ordinance, 1976	
The Ports Act, 1908	
The Territorial Water and Maritime Zones Act, 1974	
The Territorial Water and Maritime Zones Rules, 1977	
Statute of the Indo-Bangladesh Joint Rivers Commission, 1972	To maintain fresh water flow
The Canals Act, 1864	
The Embankment and Drainage Act, 1952	
The Irrigation Act, 1876	
International treaties	
International Conference for the Protection of Birds, 1950	Conservation of floral and faunal diversity, and habitat protection
International Plant Protection Convention, 1951	
Plant Protection Agreement for the South East Asia and Pacific Region, 1956	
Convention on Wetlands of International Importance, Especially as Waterfowl Habitat (Ramsar Convention), 1971	
Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), 1973	
Convention on the Conservation of Migratory Species of Wild Animals, 1979	
Convention on Biological Diversity, 1992	
FAO Code of Conduct for Responsible Fisheries, 1995	
International Convention for the Prevention of Pollution of the Sea by Oil, 1954	Environmental protection
International Convention on the Establishment of an International Fund for Compensation of Pollution Damage, 1971	Control pollution load, and environmental protection
Convention on the Prevention of marine Pollution by Dumping of Wastes and Other Matters, 1972	
International Convention for the Prevention of Pollution from Ships (MARPOL), 1973 and Protocol relating to this Convention, 1978	
United Nations Convention on the Law of the Seas, 1982	
International Convention on Oil Pollution Preparedness, Responses and Cooperation, 1990	

Table 10 (continued)

Rules and regulations	Key concerns related to Sundarbans
Convention on the Continental Shelf, 1958	To protect marine environment
Global Programme of Action on the Protection of the Marine Environment for Land-based Activities, 1995	
Convention Concerning the Protection of the World Cultural and Natural Conservation of critical ecosystem Heritage, 1972	Conservation of critical ecosystem
Convention Concerning the Protection of the World Cultural and Natural Heritage, 1994	
United Nations Conference on Environment and Development, 1992	Environmental protection
United Nations Framework Convention on Climate Change, 1992	Mitigation of the impacts of climate change
Code of Conduct for Sustainable Management of Mangrove Ecosystems, 2003	Sustainable management of mangroves, and conservation of critical ecosystem

tion, agriculture rehabilitation such as; saline tolerant species, cash grants and microcredit can be helpful for reduction on forest dependency.

iv. Forest monitoring and evaluation: Zoning of Sundarbans according to vulnerability, estimation of forested areas and inventory of forest resources using satellite based monitoring systems, ecosystem health and liveliness, ensuring security and management actions, monitoring of timber including fuel wood, pollution control, survey of forest regeneration should be done. Besides, unrestricted use of agrochemicals, and random discharge of industrial and sewage effluent should be controlled.

v. Ecological restoration and regeneration: Ecological restoration is very essential to protect the threatened species. It can be evolved by improving and promoting effective regeneration, protecting threatened species, ensure freshwater flow, develop ecotourism, development of forest area and forest cover. It is very much important to monitor rivers and marine water quality to develop healthy mangrove ecosystem. Proper guidelines should be introduced, for the treatment and removal of oil and oily substances discharged from the Mongla port and Khulna municipal area. Moreover, cost effective and eco-friendly techniques should be introduced for pollution control and remediation.

vi. Adequate policy, legal and institutional framework: Formulation of proper rules and regulations, capacity building and training for respective institutions and personnels, attempts to reduce the threats to forests, ensure mechanism for protection, management and benefit sharing among the stakeholders, accountability and financial transparency are very much important for forest management. Despite many laws and regulations (which already exist), but due to lack of proper implementation of these, forest sectors are highly vulnerable. Therefore, it is urgently required to implement the guidelines by the concerned authorities. It is also required that time to time the policies and laws should be updated for better management according to the demands.

vii. Disaster management program: Natural disasters are one of the main reasons hindering the Sundarbans forest management. Proper forecasting, warning and evacuation, pre-disaster planning, inter communication among the relevant organizations, media communication, and disaster aid for the local people may be helpful to protect the forest from adverse effects of natural disasters.

viii. Scientific research and planning: For long term sustenance of the Sundarbans mangrove, adequate scientific research is essential (Fig. 5). Without proper scientific understanding it will not be possible to recover the degraded areas of the forest. Eco-friendly and green technologies for pollution and disease control should be emphasized upon.

Furthermore, it is necessary to protect the forest from illegal encroachment and poaching of wildlife. It is also essential to recruit honest and enthusiastic forestry professionals. Moreover, widespread education to promote the importance of mangroves and its sustenance should be the priority of government and non-government organizations.

Conclusion

The Sundarbans are unique mangrove ecosystems in the world with considerable ecological and economic values. They provide different resources and services to the mankind since long time. But nowadays, the ecosystem of Sundarbans is under threat, due to various natural and man-made pressures. Among the identified causes, overexploitation, coastal land use change, pollution, increased water salinity

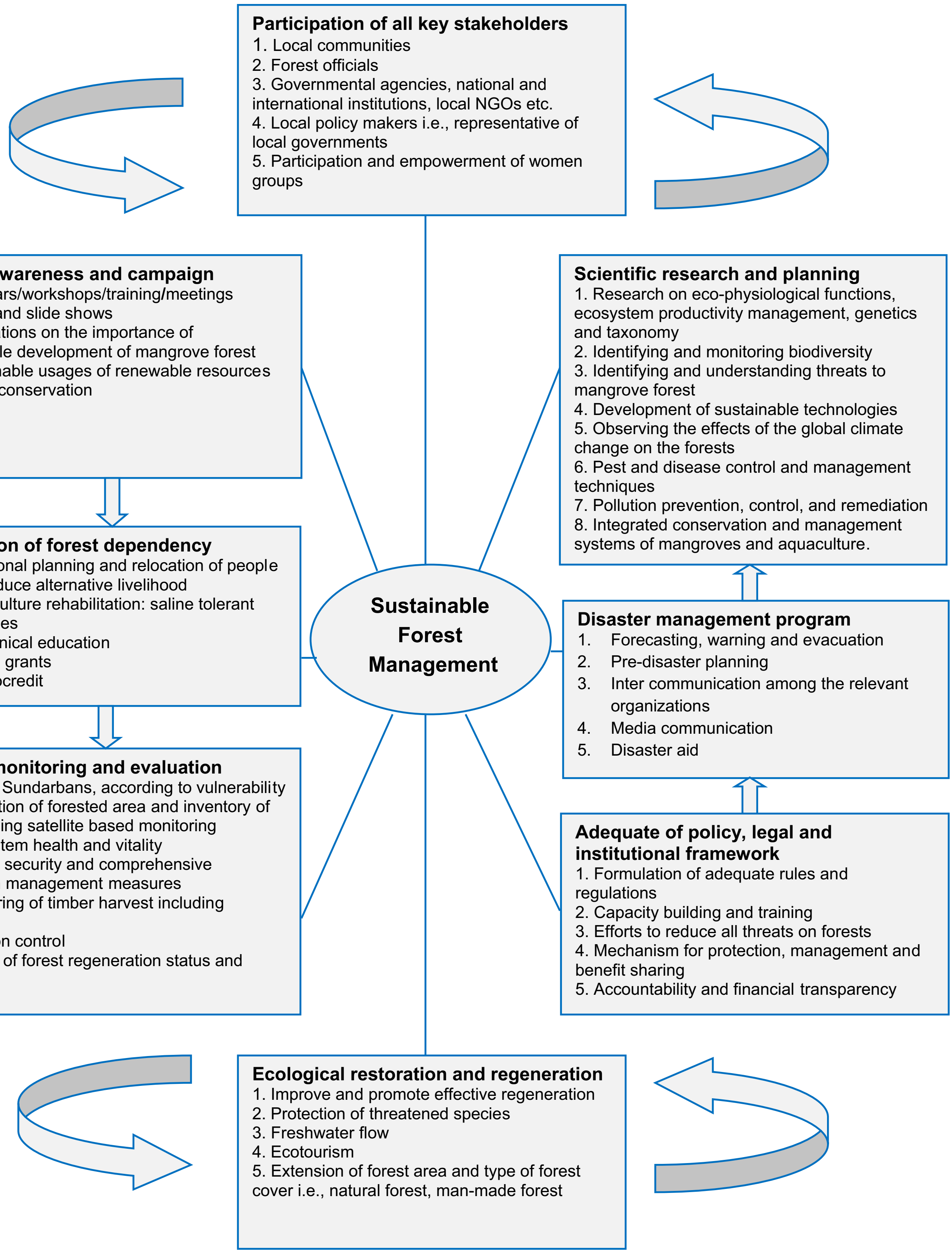

Fig. 5 Sustainable management approach for Sundarbans mangrove forest

and natural disasters are the main threat to the ecosystem of Sundarbans. The deterioration of mangroves can lead to serious impacts including decline in biodiversity, genetic erosion, extinction, and changes in the natural biogeochemistry. Although government has made several forest policies, laws and management plans to protect the Sundarbans mangroves, but due to lack of proper monitoring and integration, these are not very successful. To conserve and protect this vital ecosystem, it is essential to develop and implement suitable management strategies for sustainable future. In these circumstances, proposed management approach by refining the existing strategies and combining updated information may be helpful for sustenance of Sundarbans. This has to include an extensive combination of management systems that may effectively be practiced in Sundarbans, and similar ecosystems around the globe.

Acknowledgements The authors would like to acknowledge Ms. Tanjena Rume for her inspiration and support for this study. Authors are also thankful to the editor and anonymous reviewers who help for the current shape of the paper by their constructive and insightful comments and suggestions.

References

Abdullah AN, Myers B, Stacey N, Zander KK, Garnett ST (2017) The impact of the expansion of shrimp aquaculture on livelihoods in coastal Bangladesh. Environ Dev Sustain 19:2093–2114

Aheto DW, Kankam S, Okyere I, Mensah E, Osman A, Jonah FE, Mensah JC (2016) Community-based mangrove forest management: implications for local livelihoods and coastal resource conservation along the Volta estuary catchment area of Ghana. Ocean Coast Manag 127:43–54

Ahmed K, Ali MS (2004) Status of heavy metal pollution in Sundarban mangrove forest, a coastal wetland of upper Bay of Bengal. Otsuchi Mar Sci 27:53–54

Ahmed K, Mehedi Y, Haque R, Mondol P (2011) Heavy metal concentrations in some macrobenthic fauna of the Sundarbans mangrove forest, south west coast of Bangladesh. Environ Monit Assess 177:505–514

Akhtaruzzaman AFM (2000) Mangrove forestry research in Bangladesh. In: Proceedings for the UNU international workshop Asia–Pacific Cooperation on Research for Conservation of Mangroves, Okinawa, 26–30 March 2000

Alam MS (2002) Ban, Matshay o Pashu-Pakhi Bishoyok Ain (in Bengali). Bangladesh Law Book Company, Dhaka

Ali M, Kabir MA, Hoque ATMR (2006) People, policy, and perpetuity: sustainability indicators of Bangladesh forestry. Electron Green J. http://escholarship.org/uc/item/2c34v67q

Anon (2010) CBD fourth national report-Bangladesh (Part II, English version) Fourth national report to the convention on biological diversity: fourth national report (biodiversity national assessment and programme of action 2020)—Department of Environment. Ministry of Environment and Forests, Dhaka

Arora P, Bhardwaj R, Kanwar M (2010) 24-Epibrassinolide induced antioxidative defense system of *Brassica juncea* L. under Zn metal stress. Physiol Mol Biol Plants 16(3):285–293

Asmat GMS (2001) Bangladesher Bilupta Bannyaprani (extinct wildlife of Bangladesh). Bangla Academy, Dhaka, p 184

Aziz MA (2013) Threats to the Bangladesh Sundarban. Report of rediscovering Sundarbans, Dhaka

Aziz A, Paul AR (2015) Bangladesh Sundarbans: present status of the environment and biota. Diversity 7:242–269

Banglapedia (2010) National encyclopedia of Bangladesh. http://banglapedia.net.english/index.htm

Bhowmik AK, Cabral P (2013) Cyclone Sidr impacts on the Sundarbans floristic diversity. Earth Sci Res 2(2):62–79

Bhuiyan MAH, Islam SMD, Azam G (2017) Exploring impacts and livelihood vulnerability of riverbank erosion hazard among rural household along the river Padma of Bangladesh. Environ Syst Res 6:25. https://doi.org/10.1186/s40068-017-0102-9

Borrell A, Tornero V, Bhattacharjee D, Aguilar A (2016) Trace element accumulation and trophic relationships in aquatic organisms of the Sundarbans mangrove ecosystem (Bangladesh). Sci Tot Environ. https://doi.org/10.1016/j.scitotenv.2015.12.046

Chaffey DR, Miller FR, Sandom KH (1995) A forest inventory of the Sundarbans, Bangladesh. Land Resources Development Centre, Surrey, p 196

Choudhury JK (1997) Sustainable management of coastal mangrove forest. In: Development and social needs. XI World forestry congress, vol 6, T.38.6, Antalya

Chowdhury AH (2012) Environmental impact of coal based power plant of Rampal on the Sundarbans and surrounding areas. In: Environmental impacts assessment (EIA) report, pp 14. https://www.banktrack.org/download/annex_2_eia_dr_abdullah_harun_et_et_pdf/annex-2_eia_dr._abdullah_harun_et_et.pdf. Assessed 19 July 2017

Chowdhury RA, Ahmed I (1994) History of forest management in Bangladesh. In: Hussain Z, Acharya G (eds) Mangroves of the Sundarbans. IUCN Wetlands Program, Switzerland, pp 155–180

Chowdhury A, Maiti SK (2016) Identifying the source and accessing the spatial variations, contamination status, conservation threats of heavy metal pollution in the river waters of Sundarban biosphere reserve. J Coast Conserv, India. https://doi.org/10.1007/s11852-016-0436-x

Clifford HC (1985) Semi-intensive shrimp farming. In: Chamberlain GW, Haby MG, Miget RJ (eds) Shrimp farming manual. Corpus Christi/Texas A&M AgriLife Extension Service, IV, Texas, pp 15–42

Das BC (2013) Invertebrates and their ecosystem services in Bangladesh Sundarban. Rediscovering Sundarbans, Dhaka

Das B, Bandyopadhyay A (2013) Eco-tourism of Sundarban in Gangetic delta. Int J Sci Eng Res 4(5):937 (ISSN 2229-5518)

Das CS, Mandal RN (2016) Coastal people and mangroves ecosystem resources vis-à-vis management strategies in Indian Sundarban. Ocean Coast Manag 134:1–10

Das S, Vincent JR (2009) Mangroves protected villages and reduced death toll during Indian super cyclone. Proc Natl Acad Sci USA 106:7357. https://doi.org/10.1073/pnas.081044010

Dasgupta S, Sobhan I, Wheeler D (2017) The impact of climate change and aquatic salinization on mangrove species in the Bangladesh Sundarbans. Ambio 46:680–694

De TK, De M, Das S, Ray R, Ghosh PB (2010) Level of heavy metals in some edible marine fishes of mangrove dominated tropical estuarine areas of Hooghly river, North East coast of Bay of Bengal, India. Bull Environ Contam Toxicol 85:385–390

Deb M, Ferreira CM (2017) Potential impacts of the Sunderban mangrove degradation on future coastal flooding in Bangladesh. J Hydro Environ Res 17:30–46

Department of Forest (DoF) (2014) The list of the adjacent villages to the Sundarbans reserved forest and product collects. Office of the Conservator of Forests, Khulna Circle

Dutta D, Das PK, Paul S, Sharma JR, Dadhwal VK (2015) Assessment of ecological disturbance in the mangrove forest of Sundarbans

caused by cyclones using MODIS time-series data (2001–2011). Nat Hazards. https://doi.org/10.1007/s11069-015-1872-x
FAO (2004) Food and Agriculture Organization (FAO), state of World's forests 2003. FAO, Rome
Fattorini D, Sarkar SK, Regoli F, Bhattacharya BD, Rakshit D, Satpathy KK, Chatterjee M (2013) Levels and chemical speciation of arsenic in representative biota and sediments of a tropical mangrove wetland, India. Environ Sci Process Impacts 15:773–782
FRI (1994) Macher Upor kitnashoker bishcria. Fish Research Institute, The Pioneer Printing Press Limited, Dhaka
Ghosal TK, Kaviraj A, Das BK (1997) Preliminary observation of heavy metal speciation in some brackish water ponds of Kakdwip and Tona of Sunderban, India. Proc Zool Soc Calc (India) 50:146–152
GoB (1993) Government of Bangladesh, Forestry Master Plan (Main Plan). Ministry of Environment and Forests. Peoples Republic of Bangladesh, Dhaka
Gopal B, Chauhan M (2006) Biodiversity and its conservation in the Sundarban mangrove ecosystem. Aquat Scis 68:338–354
Guhathakurta H, Kaviraj A (2000) Heavy metal concentration in water, sediment, shrimp, *Penaeus monodon* and mullet, *Liza parsia* in some brackish water ponds of Sunderban, India. Mar Pollut Bull 40:914–920
Guzmán HM, Jiménez CE (1992) Contamination of coral reefs by heavy metals along the Caribbean coast of Central America (Costa Rica and Panama). Mar Pollut Bull 24:554–561
Hance J (2016) Thousands to march against coal plant threat to Bangladesh's Sundarbans forest. Guardian (ISSN 0261-3077). https://www.theguardian.com/environment/2016/mar/02/thousands-to-march-protest-coal-plant-threat-bangladeshs-sundarbans-forest. Assessed 27 Jan 2017
Harris RR, Santos MC (2000) Heavy metal contamination and physiological variability in the Brazilian mangrove crabs *Ucides cordatus* and *Callinectes danae* (Crustacea: Decapoda). Mar Biol 137:691–703
Hoq ME (2008) Sundarbans mangrove: fish and fisheries ecology, resources, productivity and management perspectives. Graphic Media, Dhaka, p 271
Hossain GM, Bhuiyan MAH (2016) Spatial and temporal variations of organic matter contents and potential sediment nutrient index in the Sundarbans mangrove forest, Bangladesh. KSCE J Civ Eng 20(1):163–174
Hossain MS, Kahn AYS (2001) Trace metals in Penaeid shrimp and spiny lobster from the Bay of Bengal. Sci Asia 27:165–168
Hossain MS, Uddin MJ, Fakhruddin ANM (2013) Impacts of shrimp farming on the coastal environment of Bangladesh and approach for management. Rev Environ Sci Biotechnol 12:315–332
Hossain MS, Dearing JA, Rahman MM, Salehin M (2015) Recent changes in ecosystem services and human well-being in the Bangladesh coastal zone. Reg Environ Change. https://doi.org/10.1007/s10113-014-0748-z
Hussain SG (2013) An introduction to the coasts and the Sundarbans. In: Gain P (ed) Shores of tears. Society for Environment and Human Development (SEHD), pp 01–19. ISBN 978-984-8952-05-4
Hussain Z, Acharya G (1994) Mangrove of the Sundarbans. Volume 2: Bangladesh. IUCN – Bangkok, Dyna Print, Thailand
Iftekhar MS, Islam MR (2004) Degeneration of Bangladesh's Sundarban mangroves: a management issue. Int For Rev 6(2):123–135
Iftekhar MS, Saenger P (2008) Vegetation dynamics in the Bangladesh Sundarbans mangroves: a review of forest inventories. Wet Ecol Manag 16:291–312
Iftekhar MS, Takama T (2008) Perceptions of biodiversity, environmental services, and conservation of planted mangroves: a case study on Nijhum Dwip Island, Bangladesh. Wet Ecol Manag 16(2):119–137
Islam MS (2011) Biodiversity and livelihoods: a case study in Sundarbans reserve forest, world heritage and Ramsar site (Bangladesh). Unpublished master's thesis, University of Klagenfurt, Austria
Islam SMD (2013) Evaluation of environmental and socio-economic impact due to cyclone Aila, present condition and adaptation practices in Shyamnagar, Satkhira of Bangladesh. Unpublished undergraduate thesis, Department of Environmental Sciences, Jahangirnagar University, Dhaka
Islam SMD, Bhuiyan MAH (2016) Impact scenarios of shrimp farming in coastal region of Bangladesh: an approach of an ecological model for sustainable management. Aquacult Int 24(4):1163–1190. https://doi.org/10.1007/s10499-016-9978-z
Islam MSN, Gnauck A (2009) Threats to the Sundarbans mangrove wetland ecosystems from transboundary water allocation in the Ganges Basin: a preliminary problem analysis. Int J Ecol Econ Stat 13:64–78
Islam KMN, Islam MN (2011) Economics of extraction of products from Sundarbans reserve forest. Bangladesh J Agric Econ 1&2:29–53
Islam SMD, Uddin MJ (2015) Impacts, vulnerability and coping with cyclone hazard in coastal region of Bangladesh: a case study on Kalapara upazila of Patuakhali district. Jahangirnagar Univ Environ Bull 4:11–30
Islam MS, Wahab MA (2005) A review of the present status and management of mangrove wetland habitat resources in Bangladesh with emphasis on mangrove fisheries and aquaculture. Hydrobiologia 542:165–190
Islam SMD, Bhuiyan MAH, Ramanathan AL (2015) Climate change impacts and vulnerability assessment in coastal region of Bangladesh: a case study on Shyamnagar upazila of Satkhira district. J Clim Change 1(1–2):37–45. https://doi.org/10.3233/JCC-150003
Islam MS, Huda ME, Islam SMD (2016) Changing cropping pattern in disaster prone region of Bangladesh: a case study. Jahangirnagar Univ Environ Bull 5:25–36
IUCN Bangladesh (2003) Conservation monitoring of Sundarban biodiversity. In: Biodiversity health status workshop proceedings, IUCN Bangladesh Country Office, Dhaka
Janaki-Raman D, Jonathan MP, Srinivasalu S, Armstrong-Altrin JS, Mohan SP, Ram-Mohan V (2007) Trace metal enrichments in core sediments in Muthupet mangroves, SE coast of India: application of acid leachable technique. Environ Pollut 145:245–257
Khan MAR (1986) Wildlife in Bangladesh mangrove ecosystem. J Bombay Nat Hist Soc 83(1):32–48
Khan R (2013) Sundarban, rediscovering Sundarban: the mangrove beauty of Bangladesh. Karunangshu Barua, Nymphea Publication, Dhaka
Khanom S, Buckley RC (2015) Tiger tourism in the Bangladesh Sundarbans. Ann Tour Res 55:178–180. https://doi.org/10.1016/j.annals.2015.09.006
Khanom S, Shah MAR and Chaudhary A (2011) Towards ecotourism: issues of current tourism practices in the Sundarban mangrove forest, Bangladesh. In: Paper presented in peace, environment and tourism conference 2011, Pokhara, 20–21 September 2011
Kumar C (2013) Bangladesh power plant struggle calls for international solidarity. The Huffington Post, New York
Kumar A, Ramanathan AL (2015) Speciation of selected trace metals (Fe, Mn, Cu and Zn) with depth in the sediments of Sundarban mangroves: India and Bangladesh. J Soils Sediments 15:2476–2486
Kumar B, Sajwan KS, Mukherjee DP (2012) Distribution of heavy metals in valuable coastal fishes from North East coast of India. Turk J Fish Aquat Sci 12:81–88
Kumar A, Ramanathan AL, Prasad MBK, Datta D, Kumar M, Sappal SM (2016) Distribution, enrichment, and potential toxicity of trace metals in the surface sediments of Sundarban mangrove ecosystem, Bangladesh: a baseline study before Sundarban oil

spill of December, 2014. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-016-6086-6
MacFarlane GR, Pulkownik A, Burchett MD (2003) Accumulation and distribution of heavy metals in the grey mangrove, *Avicennia marina* (Forsk.) Vierh.: biological indication potential. Environ Pollut 123:139–151
MacFarlane GR, Koller CE, Blomberg SP (2007) Accumulation and partitioning of heavy metals in mangroves: a synthesis of field based studies. Chemosphere 69:1454–1464
Machado W, Moscatelli M, Rezende LG, Lacerda LD (2002) Mercury, zinc, and copper accumulation in mangrove sediments surrounding a large landfill in southeast Brazil. Environ Pollut 120:455–461
Mahadevia K, Vikas M (2012) Climate change impact on the Sundarbans: a case study. Int Sci J Environ Sci 2(1):7–15
Malik A, Mertz O, Fensholt R (2017) Mangrove forest decline: consequences for livelihoods and environment in South Sulawesi. Reg Environ Change 17:157–169
Mandal AK (2003) The Sundarban of India: a development analysis. Indus Publishing, New Delhi, p 260
MAP (2010) Mangrove action Project, USA. http://mangroveactionproject.org/
Mirza MMQ (1998) Diversion of the Ganges water at Farakka and its effects on salinity in Bangladesh. Environ Manag 22(5):711–722
Mitra A, Barua P, Zaman S, Banerjee K (2012) Analysis of trace metals in commercially important crustaceans collected from UNESCO protected world heritage site of Indian Sundarbans. J Fish Aquat Sci 12:53–66
MoEF (1993) Forestry master plan, main plan 1993–2013, vol I. Ministry of Environment of Forests, Asian Development Bank (TA no. 1355-BAN). Government of Bangladesh
MOEF (Ministry of Environment and Forests) (2010) Integrated resource management plans for the Sundarbans (2010–2020). Forest Department, Dhaka
Mukhtar I, Hannan A (2012) Constrains on mangrove forests and conservation projects in Pakistan. J Coast Conserv 16:51–62
Nandy P, Das S, Ghose M, Spooner-Hart R (2007) Effects of salinity on photosynthesis, leaf anatomy, ion accumulation and photosynthetic nitrogen use efficiency in five Indian mangroves. Wetl Ecol Manag 15:347–357
Neogi SB, Dey M, Kabir SML, Masum SJH, Kopprio G, Yamasaki S, Lara R (2016) Sundarban mangroves: diversity, ecosystem services and climate change impacts. Asian J Med Biol Res 2(4):488–507
Ong-Che R (1999) Concentration of 7 heavy metals in sediments and mangrove root samples from Mai Po, Hong Kong. Mar Pollut Bull 39:269–279
Pahlowan EU, Hossain ATMS (2015) A disparity between erosional hazard and accretion of the Sundarbans with its adjacent east coast, Bangladesh: a remote sensing and GIS approach. In: Michel U, Schulz K, Ehlers M, Nikolakopoulos KG, Civco D (eds) Earth resources and environmental remote sensing/GIS applications VI. Proceedings of the SPIE, vol 9644, p 96441G. https://doi.org/10.1117/12.2196386
Paul A, Ray R, Kamila A, Jana S (2017) Mangrove degradation in the Sundarbans. In Finkl CW, Makowski C (eds) Coastal wetlands: alteration and remediation, vol 21, pp 357–392. Springer, Cham. http://doi.org/10.1007/978-3-319-56179-0_11
Payo A, Mukhopadhyay A, Hazra S, Ghosh T, Ghosh S, Brown S, Nicholls RJ, Bricheno L, Wolf J, Kay S, Lázár AN, Haque A (2016) Projected changes in area of the Sundarban mangrove forest in Bangladesh due to SLR by 2100. Clim Change. https://doi.org/10.1007/s10584-016-1769-z
Perdomo L, Ensminger I, Fernanda Espinosa L, Elster C, Wallnerkersanach M, Schnetter ML (1999) The mangrove ecosystem of the Ciénaga Grande de Santa Marta (Colombia): observations on regeneration and trace metals in sediment. Mar Pollut Bull 37:393–403
PMA (2005) Pollution and its management approach. Ministry of Water Resources, Government of the Peoples Republic of Bangladesh, WP 043, pp 14–16
Preda M, Cox ME (2002) Trace metal occurrence and distribution in sediments and mangroves, Pumicestone region, southeast Queensland, Australia. Environ Int 28:433–449
Rahman S (2011) Impacts of climate change on ecological composition and biodiversity of Sundarban, Bangladesh. In: Paper presented at a conference in the Philippines. http://www.ched.gov.ph/chedwww/index.php/eng/content/download/1792/9300/file/Impacts_CC_Sundarban_Shahriar_Rahman.pdf. Accessed 15 July 2012
Rahman R (2014) Causes of biodiversity depletion in Bangladesh and their consequences on ecosystem services, pp 1–53
Rahman MR, Hossain MB (2015) Changes in land use pattern at Chakaria Sundarbans mangrove forest in Bangladesh. Bangladesh Res Public J 11(1):13–20
Rahman MM, Rahaman MM (2017) Impacts of Farakka barrage on hydrological flow of Ganges River and environment in Bangladesh. Sustain Water Resour Manag. https://doi.org/10.1007/s40899-017-0163-y
Rahman N, Billah MM, Chaudhury MU (1979) Preparation of an up to date map of Sundarban forests and estimation of forest areas of the same by using Landsat imageries. In: Second Bangladesh national seminar on remote sensing, Dhaka, 9–15 December 1979
Rahman MA, Haque AKF, Rakkibu MG, Misbahuzzaman K (2003) Study on top dying of Sundri (*Heritiera fomes*) and its management in the Sundarbans, vol I. In: Main report
Rahman MM, Chongling Y, Islam KS, Haoliang L (2009) A brief review on pollution and ecotoxicologic effect on Sundarbans mangrove ecosystem in Bangladesh. Int J Environ Eng 1(4):369–382
Rahman MM, Rahman MM, Islam KS (2010) The causes of deterioration of Sundarban mangrove forest ecosystem of Bangladesh: conservation and sustainable management issues. AACL Bioflux 3(2):77–90
Rahman SH, Islam SMD, Rume T (2016) Seawater intrusion in coastal region of Bangladesh: causes, impacts and adaptation. J State Univ Bangladesh (special issue on environment) 6(2):44–63
Rahman MTU, Rasheduzzaman M, Habib MA, Ahmed A, Tareq SM, Muniruzzaman SM (2017) Assessment of fresh water security in coastal Bangladesh: an insight from salinity, community perception and adaptation. Ocean Coast Manag 137:68–81
Ranjan RK, Ramanathan AL, Singh G, Chidambaram S (2008) Assessment of metal enrichments in tsunamigenic sediments of Pichavaram mangroves, southeast coast of India. Environ Monit Assess 147:389–411
Ray AK, Tripathy SC, Patra S, Sarma VV (2006) Assessment of Godavari estuarine mangrove ecosystem through trace metal studies. Environ Int 32:219–223
Roy TK, Hossain ST (2015) Role of Sundarbans in protecting climate vulnerable coastal people of Bangladesh. Clim Change 1(1):40–44
Roya AKD, Gowb J (2015) Attitudes towards current and alternative management of the Sundarbans mangrove forest, Bangladesh to achieve sustainability. J Environ Plan Manag 58(2):213–228
Saadi MLK (2010) Hurricane Sidr claims beautiful mangroves. http://www.islamonline.net
Sandilyan S, Kathiresan K (2014) Decline of mangroves—a threat of heavy metal poisoning in Asia. Ocean Coast Manag 102:161–168
Sanyal P (1983) Mangrove tiger land: the Sundarbans of India. Tigerpaper 10(3):1–4

Sarker SU (1993) Ecology of wildlife UNDP/FAO/BGD/85/011. In: Field document No. 50. Institute of Forestry and Environmental Sciences, Chittagong
Sarwar MGM (2015) Sundari protecting the biodiversity of the Sundarbans by reducing human pressure. Concern Worldwide Bangladesh, Dhaka, p 1212
Scott DA (1989) A directory of Asian wetlands. IUCN, Gland
Sharif AKM, Mustafa AI, Mirza AH, Safiullah S (1991) Trace metals in tropical marine fish from the Bay of Bengal. Sci Tot Environ 107:135–142
Shigenaka G (2002) Oil spills in mangroves, planning and response condition. National Oceanic and Atmospheric Administration NOAA Ocean Service, New York, p 23
Singh G, Ramanathan AL, Prasad MB (2005) Nutrient cycling in mangrove ecosystem: a brief overview. Int J Ecol Environ Sci 30:231–244
Sundarbans Oil Spill Assessment (SOSA) (2014) Joint United Nations/Government of Bangladesh Mission (December 2014). http://reliefweb.int/report/bangladesh/sundarbans-oil-spill-assessment-joint-united-nationsgovernment-bangladesh-mission
Tam NF, Wong YS (2000) Spatial variation of heavy metals in surface sediments of Hong Kong mangrove swamps. Environ Pollut 110:195–205
The Daily New Age (2016) New Age (editorial) more reasons to stop Rampal power plant, Dhaka, 26 May 2016. Archived from the original on 4 March 2016 Daily English newspaper in Bangladesh. http://mybangla24.com/newsage_online_bangla_newspaper.php
The Daily Star (2014) Bangla news paper. http://www.thedailystar.net/oil-spills-into-river-as-tanker-sinks-at-sundarbans-54377
Uddin MS, Shah MAR, Khanom S, Nesha MK (2013) Climate change impacts on the Sundarbans mangrove ecosystem services and dependent livelihoods in Bangladesh. Asian J Conserv Biol 2(2):152–156
UNEP (2001) Bangladesh: state of-the-environment report. http://www.rrcap.unep.org/pub/soe/bangladeshsoe.cfm
UNESCO (2007) Climate change threatens UNESCO world heritage sites, UN. http://whc.unesco.org/en/news/319
Uta B, Marion G, Boris K, Gesche K, Rubén L, Ulrich SP, Dirk S, Matthias W (1999) An integrated approach to mangrove dynamics and management. J Coast Conserv 5:125–134
Vivekanandan E, Hermes R, O'Brien C (2016) Climate change effects in the Bay of Bengal large marine ecosystem. Environ Dev 17:46–56
WCMC (2001) Protected areas program: World heritage sites. UNEP World Conservation Monitoring Centre, Cambridge. http://www.unep-wcmc.org/sites/wh/sundarb.html
WWF (2007) Rising sea levels threaten to wash away entire nations. http://www.panda.org