Earth Science & Climatic Change

Chaudhuri et al., J Earth Sci Clim Change 2015, 6:4
DOI: 10.4172/2157-7617.1000270

Research Article | Open Access

A Review of Threats and Vulnerabilities to Mangrove Habitats: With Special Emphasis on East Coast of India

Ghosh S[1], Bakshi M[1], Bhattacharyya S[2], Nath B[3] and Chaudhuri P[1]*

[1]*Department of Environmental Science, University of Calcutta, West Bengal, India*
[2]*School of Environmental Studies, Jadavpur University, West Bengal, India*
[3]*School of Geosciences, University of Sydney, Sydney, NSW 2006, Australia*

Abstract

Mangroves are one of the most threatened ecosystems worldwide located within the intertidal zones of tropics and subtropics. They provide both ecologic and economic benefits to coastal communities. They safeguard community lives and properties in coastal areas during storm surges, hurricanes, cyclones and tsunamis. Global estimate shows decline in mangrove vegetal covers to ~150,000 sq. km. Degradation of mangrove ecosystems in India are mainly due to continuous increase in anthropogenic activities such as conversion of mangrove wetlands for aquaculture and destruction of mangrove forest for timber. In the coastal areas inhabitants are at risks of losing their livelihood and ecological communities are in the verge of extinction. The effective conservation and management of mangrove habitats should be considered in association with local community participation and application of remote sensing technique and Geographic Information System (GIS)-based comprehensive database approach. We reviewed threats and vulnerabilities to mangrove habitats around the world with a special emphasis in east coast of India. We also reviewed current mangrove management practices. We discussed the importance of acquisition/assessment of remote sensing data for GIS-based effective mangrove management approach in remote Indian coasts. A combination of remote sensing and GIS-based approach will have significant ecologic and economic benefits by gaining real-time data from inaccessible areas. This strategy has valuable implications to other remote/threatened mangrove wetlands worldwide.

Keywords: Mangrove habitat; Anthropogenic stress; Climatic vulnerability; Management

Introduction

Mangroves are a group of highly adaptive salt tolerant plant species inhabiting intertidal zones of tropical and subtropical coastlines [1,2]. They require temporary supply of fresh, non-saline water for growth and survival [3-6]. Mangrove habitats (sporadic or dense strands and multi-/mono-species) are reported from 124 countries between 30˚N and 30˚S latitudes [7]. The global mangrove cover has been estimated to be approximately 150,000 sq. km [8-10]. Mangroves are broadly classified into two groups, i) true mangroves and ii) mangrove associates [11]. True mangrove species only grow in intertidal zones, e.g., Heritiera fomes, Bruguiera gymnorrhiza, Avicennia alba and Rhizophora mucronata, whereas mangrove associates can survive in both littoral and terrestrial environments, e.g., Hibicus tilisaceus, Suaeda nudiflora and Thespesia populnea. Mangroves possess important ecological and socio-economical functions: i) they increase soil/sediment accretion and stabilize shorelines [1], ii) they trap nutrient and heavy metals and facilitate improved water quality [12-14], iii) they serve as a reserve of food, fuel and fodder for coastal communities [15,16], iv) some mangrove species have medicinal values [17-19], v) mangrove habitats act as a breeding ground for different types of amphibians, fishes, prawn, shellfishes and crustaceans [20], vi) they serve as a home for large numbers of mammals, birds and reptiles [21], and vii) they act as a barrier against natural disasters in coastal areas, e.g., cyclones, typhoons or tsunamis [22-24]. Despite their ecologic, social and economic functions, these ecosystems are continuously under the threat due to anthropogenic activity and climatic vulnerability. As a consequence the species diversity index of mangroves is gradually decreasing in many areas [18]. Loss of mangroves throughout the world may reach up to 60% by 2030 [23,25-27]. Mangrove forests are continuous declining at a speedy rate (1 to 2% per year), however at a threatening level in the developing countries where they found in abundances [10,28]. Therefore, it is important to generate awareness among coastal inhabitants regarding beneficial aspect of mangroves and implementation of a proper management strategy to protect these habitats from further destruction. The objective of this study is to review current threats and vulnerabilities to mangrove ecosystems around the world with a special emphasis to east coast of India and summarizes key management considerations for protection. We highlighted the importance of remote sensing data and Geographic Information System (GIS) technology to gain real-time information from remote/inaccessible areas in order to successfully manage these fragile coastal ecosystems.

Distributions of mangrove forest

Global mangrove cover: Total mangrove cover globally is 156,220 sq. km which constituting 62,880 sq. km in Asia, 30,270 sq. km in Africa, 23,870 sq. km in North and Central America, 21,610 sq. km in South America and 17,590 sq. km in Oceania (Table 1). Indonesia alone constitutes 23% of global mangrove cover followed by Australia (7.1%) and Brazil (7%). Food and Agriculture Organization (FAO) of the United Nations estimated reduction in mangrove cover by 18% within a span of last three decades. In Asia, Africa, Oceania and North and Central America, mangrove cover was reduced by 19%. Whereas,

***Corresponding author:** Chaudhuri P, Department of Environmental Science, University of Calcutta, West Bengal, India, Tel: +91 9831140980; E-mail: punarbasu_c@yahoo.com

Received March 02, 2015; **Accepted** March 18, 2015; **Published** March 28, 2015

Citation: Chaudhuri P, Ghosh S, Bakshi M, Bhattacharyya S, Nath B (2015) A Review of Threats and Vulnerabilities to Mangrove Habitats: With Special Emphasis on East Coast of India. J Earth Sci Clim Change 6: 270. doi:10.4172/2157-7617.1000270

Location	Area (sq. km)					% change
	1980	1990	2000	2005	2010	
Asia	77,690	61,960	66,270	64,660	62,880	-19
Africa	36,700	34,140	31,780	31,020	30,270	-17
North and Central America	29,510	24,160	23,100	23,420	23,870	-19
Oceania	21,810	18,600	18,410	15,370	17,590	-19
South America	22,220	22,250	21,870	21,750	21,610	-2.8
Total	189,910	161,110	161,430	156,220	156,220	-18

Source: FAO (2007 and 2010).

Table 1: Worldwide distribution of mangrove vegetation cover.

State/Union Territory	Area (sq. km)						% change
	1987	1993	1999	2005	2011	2013	
West Bengal	2,076	2,119	2,125	2,136	2,155	2,097	-1.01
Andhra Pradesh	495	378	397	354	352	352	28.89
Odissa	199	195	215	217	222	213	-7.04
Tamil Nadu	23	21	21	36	39	39	-69.57
East coast	3,479	3,679	3,724	3,378	3,386	3,306	4.97
Gujarat	427	419	1,031	911	1,058	1,103	-158.31
Maharashtra	140	155	108	186	186	186	-32.86
Goa	0	3	5	16	22	22	100.00
West coast	567	577	1,147	1,122	1,276	1,322	-133.16
Total	4,046	4,256	4,871	4,500	4,662	4,628	-14.38

Source: FSI (2013)

Table 2: Total mangrove vegetation cover in India.

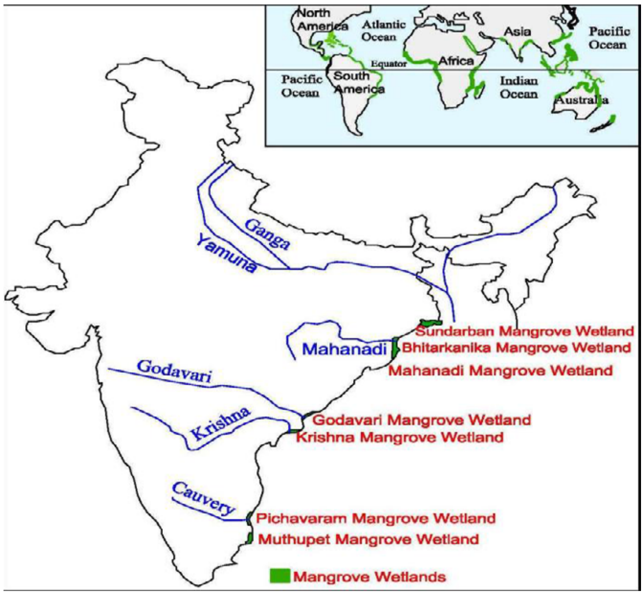

Figure 1: Distribution of mangroves throughout the world (inset) and in east coast of India (modified after National Geographic Magazine).

mangrove cover was almost remain unchanged in South America where reduction is only by 2.8% [7,9].

Indian mangrove cover: Mangrove habitat covers an area of 4,628 sq. km along Indian coastlines which comprises of ~3% of world's mangrove forests [29] (Table 2). These include 1,351 sq. km of very dense, 1,457 sq. km of moderate and 1,819 sq. km of open mangroves. Indian mangrove forest was increased over the last two decades concurrent with the strict conservation and afforestation program implemented by the Government of India to recover from decline during 1990's [29]. Major mangrove wetlands spread along the east coast and Andaman and Nicobar Island while in the west coast they are predominantly localized (Figure 1). The location and diversity of these forests are influenced by the inflow of fresh water which is more pronounced in the east coast as major rivers of the Indo-Gangetic plain and Deccan plateau discharges into Bay of Bengal. The inflow of fresh water decreases from north to south likewise decrease in species diversity and mangrove cover.

Threats and Vulnerabilities to Mangrove Ecosystems

Mangroves play a vital role in many aspects of human life (e.g., therapeutic uses, e.g., malaria, diarrhea, ulcer, skin infections, diabetes and snake bite) [17], but these ecosystems are vulnerable to anthropogenic activities and climate change [30,31]. In some coastal areas mangrove ecosystems are converted into farm lands, resorts and aquaculture [21,28,32,33]. Loss of mangroves is also a consequence of climate change, e.g., rise or fall of sea level [34,35], changing pattern and magnitude of cyclone, rainfall intensity and shoreline erosion [36]. Natural phenomenon has a lesser threat to mangrove ecosystems than anthropogenic activity [25,26,28,37]. Species diversity was decreased in many regions due to land use changes [5,38-40].

Global status

Decline in mangrove cover over the last few decades is reported from many areas worldwide. In the past few decades rapid urbanization and population growth has resulted in the reduction of mangrove forests throughout China. Chen et al. reported reduction in mangrove cover by 44% to ~220 sq. km in 2001 from >500 sq. km in 1950 [41]. Urban sewage, surface runoff from agriculture and aquaculture ponds, oil spills and change in land use are serious threats to mangroves of China [42-44]. In addition to that, traditional uses of mangroves for food, fodder, medicine, tannin and production of charcoal are a threat to these ecosystems. In Myanmar (Ayeyarwady delta), ~1,685 sq. km of mangrove wetland was cleared within a span of three decades due to agricultural expansion and fuel wood extraction [45-48]. Since 1978, anthropogenic activities mainly agriculture, shrimp farming and urbanization have destroyed more than half of the mangrove area in Segara Anakan Lagoon, Indonesia [49,50]. Major losses of mangroves in the Philippines are due to habitat conversions such as agriculture, aquaculture, industry, salt ponds and settlements. The decrease in mangrove cover from 4,500 sq. km in 1920 [51] to 1,200 sq. km in 1994 [52] can be correlated with the expansion of shrimp farming practices. However, in Australia and New Zealand, mangroves are expanding their boundaries at a constant rate over the last few decades. In Tauranga Harbour, New Zealand, mangroves have doubled their extent within a span of five decades, from 240 ha in 1943 to 545 ha in 1999 [53]. Mangrove coverage was increased by approximately 3.8%, 32.8% and 55% in Gosford (New South Wales), Botany Bay (Sydney) and Phillip Island (Victoria) from 1954 to 1995, 1956 to 1996 and 1939 to 1999, respectively [54-57]. In Brazil, nearly 500 sq. km of mangrove was cleared in the last two and half decades mainly for aquaculture and farming [7]. In Kenya, mangrove cover was reduced by 18% within a span of two and half decades at a mean rate of 0.7% per year due to inadequate legislation and habitat modifications [58]. During last decade mangrove forest was reduced by ~15 sq. km in Tanzania due to land reclamation [59]. In Bangladesh, mangroves in Sundarban have lost 45% of its coverage due to continuous encroachment due to logging, shrimp farming and natural calamities [60-62].

East coast of India

Several mangrove wetlands are located along east coast of India, especially in the state of Tamil Nadu (Pichavaram and Muthupet), Andra Pradesh (Godavari and Krishna), Orissa (Mahanadi and Bhitarkanika) and West Bengal (Sundarbans). These wetlands are the largest known continuous mangrove patches in these regions.

Pichavaram mangrove wetland: Pichavaram mangrove wetland (latitude: 11° 23’ to 11° 30’ N and longitude: 79° 45’ to 79° 50’ E) is located between Coleroon and Vellar estuary in the state of Tamil Nadu. The wetland comprises of ~11 sq. km mangrove cover [63]. The wetland is a monospecific domination of Avicennia marina (Forsk.) vierh., while other species like Rhizophora mucronata, Rhizophora apeculata and Excoecaria agalochha are also present but in low abundances [63,64]. Two distinct zones of Rhizophora and Avicennia species can be identified. Rhizophora zone occurs along the tidal creeks and channels with widths between 5 and 12 m while Avicennia zone starts behind the Rhizophora zone with widths between 20 and 90 m [65]. Human settlements along fringes depend on the wetland for their livelihood (especially fishing and fish harvesting). About 245 tonnes of prawn, fish and crabs were harvested annually [66]. Currently, the wetland is affected by regular inflow of pollutants generated from industrial discharges, agricultural runoff and sewage. Cumulative effect of these has caused reduction in mangrove cover from ~40 sq. km (at the beginning of 20th century) to 11 sq. km [63,67]. Additionally, due to heavy siltation, connectivity was lost between Pichavaram mangrove wetland and Vellar estuary which resulted in the formation of large mud flats contrary to beach formation that guards wetland from any direct interaction with the Bay of Bengal. Along with this, tidal water inflow to the wetland is reduced due to formation of new sand spit in the mouth of river Coleroon [64].

Muthupet mangrove wetland: Muthupet mangrove wetland (latitude: 10° 25’ N and longitude: 79° 30’ E) is located at the southern end of Cauvery delta (Tamil Nadu). The wetland is surrounded by mud flats in the north and Palk Strait in the south. A number of major and minor dams were constructed on the rivers of Cauvery riverine system; as a result discharge of fresh water and deposition of sediment was reduced. This has resulted in the increase in soil salinity and disappearance of mangrove species [64]. The wetland is characterized by the presence of eight mangrove species, among them Avicennia marina is the dominant. Palaeological studies reveal that Sonneratia and Rhizophora species have locally become extinct [68]. Inhabitants near forest fringes collect woods and dried twigs as fire woods. A study based on multispectral remote sensing data found nearly 15 sq. km of mangrove forest during 1988 [69]. Similar studies on wetland mapping along Cauvery delta reveals mangrove cover of 32 sq. km in 1976 which was reduced to 19 sq. km in 1989. Ponnambalam et al. found slight increase in dense mangrove cover from 10 to 12 sq. km between 1991 and 1999 which later decreased to 9.9 sq. km in 2007 due to conversion of land for aquaculture and coastal erosion [70]. FSI reported presence of 5 sq. km of dense mangrove cover and 3 sq. km of degraded mangrove in this wetland [29].

Godavari mangrove wetland: Godavari mangrove wetland (latitude: 16° 30’ to 16° 55’ N and longitude: 82° 10’ to 82° 21’ E) is located in East Godavari district of Andhra Pradesh. The wetland has 63 sq. km of dense mangrove forests and 125 sq. km of degraded mangrove forests [29]. Fifteen species of true mangroves have been identified so far in this wetland [71,72]. Godavari mangrove forests are highly enriched in natural resources. People inhabiting forest fringes rely on mangrove wetland for livelihood. They use dried twigs and woods for fire and making of boat or furniture. This mangrove forest is typically acting as a breeding ground for several species of fish and crustaceans. Report suggests that mangrove wetland is gradually converted into aquaculture farm for prawn farming. Satellite image shows conversion of 6.6 sq. km of mangrove wetland for prawn farming [21]. This has contributed to annual production of 12,000 tons of shrimp from converted mangrove wetlands [73]. An increase of 5.9 sq. km of mangrove cover was recorded between 1986 and 2001 due to sediment deposition by river Godavari and its distributaries [21].

Krishna mangrove wetland: Krishna mangrove wetland (latitude: 15° 50’ to 15° 55’ N and longitude: 80° 45’ to 80° 50’ E) spread across 158 sq. km in Guntur and Krishna district of coastal Andhra Pradesh [29]. River Krishna and its distributaries are the main source of fresh water in this wetland. Peoples living near forest fringes earn their livelihood through fishing; they also collect wood and dried twigs for raw material for construction, boat making, fencing and fuel. Coastal erosion is of serious concern in Krishna delta as erosion is a dominant process throughout the coastline while deposition occurs only in limited zones. Conversion of mangrove wetland to aquaculture leads to shoreline retreat in Krishna delta [74]. Ravishankar et al. observed natural regeneration of mangroves during 1986 to 1996, with an overall increase in mangrove cover to 16 sq. km until 2001 [75].

Mahanadi mangrove wetland: Mahanadi mangrove wetland (latitude: 20° 18’ to 20° 32’ N and longitude: 86° 41’ to 86° 48’ E) is located between Jagri Jhor in the north and river Mahanadi in the south of Orissa district. River Mahanadi and its distributaries are the main source of fresh water to this wetland. Total mangrove cover is 45 sq. km [76]. Thirty-four true mangrove species have so far reported in this wetland. Among them Avicennia officinalis, A. marina, Sonneratia apetala, Exocoecaria agallocha and Rhizophora mucronata are the dominant species. Fishing is one of the principle occupations of the people living in villages near forest fringes. Continuous increase in anthropogenic pressure has caused degradation of mangrove wetland. The discharge of wastewaters from aquaculture ponds has caused mass destruction of mangrove habitats [76]. It was estimated a total area of 69 sq. km mangrove cover (34 sq. km of dense forests and 35 sq. km of open forests) in 1973 [76]. However, within a span of three decades dense mangrove forest was increased to 36 sq. km, while open mangrove forest was decreased to 9.3 sq. km.

Bhitarkanika mangrove wetland: Bhitarkanika wildlife sanctuary (latitude: 20° 40’ to 20° 48’ N and longitude: 86° 45’ to 87° 50’ E) is the second largest mangrove forest in India, located in Kendrapara district of Orissa. The total mangrove cover is 183 sq. km [29]. Twenty-eight species of true mangroves and four species of mangrove associates have reported so far, among them Exocoecaria agallocha, Heritiera littoralis, Avicennia officinalis and Cynometra ramiflora are the most dominant species. Local inhabitants collect timber and non-timber forest resources for fire wood, house and boat making, thatching and fodder. The collection of forest wood has decreased following declaration of a wildlife sanctuary in 1975 by the Govt. of Orissa. Fishing is the main source of livelihood for majority of inhabitants living in this region. Reddy et al. estimated 180 sq. km of mangrove cover during 1973, consisting of both dense (147 sq. km) and open (33 sq. km) mangrove forests [77]. The estimate during 2004 shows no change in dense mangrove cover but open mangrove forest decreased to 18 sq. km. But due to proper restoration and rehabilitation programs the total mangrove cover was increased to 183 sq. km which includes 161 of dense mangrove and 22 sq. km open mangrove [29].

Sundarbans mangrove wetland: The Sundarbans (latitude: 21° 31’ to 22° 30' N and longitude: 88° 10' to 89° 51' E) is the home of world's largest continuous block of mangrove wetland. Sundarbans is bordered by river Hooghly in the west and river Baleshwar (in Bangladesh) in the east. River Harinbhanga demarcates Indian and Bangladesh part of Sundarbans. Indian part of Sundarbans covers an area of 4,246 sq. km [78] whereas Bangladesh part covers an area of 6,017 sq. km [79]. About thirty species of true mangroves have reported so far [80]. Sundarbans is a highly fragile ecosystem due to its complex geological and environmental settings consistent with increasing population density and climatic variability [81]. The region is vulnerable to coastal erosion and inundation due to rise in sea level. Ericson et al. reported sea level rise in the Bay of Bengal of >10 mm/year, which is the world's highest rate of sea level rise [82]. This trend was confirmed by recent report of 4.0 mm/year sea level rise in the western part and 7.8 mm/year in the eastern part [83,84]. Most of the distributaries of river Ganges has silted up and carries very little quantities of fresh water except during monsoon causing increase in salinity. Thus high salinity tolerant species, e.g., Avicennia alba and Exocoecaria agallocha are gradually replacing Heritiera fomes and Sonneratia casoelaris that require regular supply of fresh water for their growth [80]. Biodiversity of Sundarbans has exploited by humans for several decades, where conversion of mangrove wetlands to paddy cultivation or shrimp farming is a common practice. Sundarbans has many densely populated villages and local inhabitants rely on wetland forests for livelihood. Local inhabitants are involved in commercial exploitation of Heritiera fomes and Avicennia marina for boat making, poles and rafters. They collect fire wood, leaves for roofing (especially from Nipa fruticans and Phoenic paludosa), grass for fodder and fish and shrimps [80]. Local people collect honey and wax from mangroves trees, especially from Aegialitis rotundifolia, Aegicerus corniculatum, Avecennia marina and Ceriops decandra species [85]. Prior estimate reveals that Sundarban mangroves was originally covered >40,000 sq. km in coastal West Bengal and Bangladesh. Conversion of mangrove forests for cultivation was actively promoted by Turk sultans of undivided Bengal. During British colonial era (ca. 1793), Sundarbans covers an area of 19,508 sq. km. British authorities actively promoted conversion of mangrove land for cultivation. As a result, by 1870 ~2,790 sq. km and by 1930 further 2,750 sq. km of mangrove forests were converted for other land use practices. A further ~1,570 sq. km of mangroves were converted within three decades of India's independence [80,86].

Management Practices

Mangrove ecosystem is continuously facing a threat from anthropogenic activities and climate change. As a result effective conservation and management of these fragile ecosystems is required for a better environmentally sustainable future [87].

Strategies on mangrove managements

Indonesia alone constitutes ~23% of global mangrove cover [10]. Government of Indonesia passed a law to maintain 50-200 m mangrove belt along the coast to preserve the ecological functioning and natural regeneration process [50,88]. In Philippines, community-based mangrove regeneration and rehabilitation program have attained greater level of success than any other funded national and international projects [89]. The National Mangrove Committee (NMC) was formed in 1976 to design a comprehensive and integrated management program that would rationalize mangrove management procedures, and to review all aquaculture leases and timber licenses [90,91]. Since then, a number of internationally funded mangrove rehabilitation and regeneration program have been initiated by the national government of Philippines and implemented with local government and non-government organizations (NGOs). In Myanmar conservation of mangroves by means of protection are small and environmental law and regulations are largely absent [92] and rarely implemented [93,94]. The mangrove wetlands of Bangladesh (i.e., Bangladeshi part of Sundarbans) are managed by the Bangladesh Forest Department under conservation policies. The government allows mangrove dependent local communities with permits to harvest certain resources [62]. Most mangrove forests in China are distributed in the regions with highest population density which receives threats from local economic growth over last three decades. In 1976, Mai Po wetland in Hong Kong was established as a first mangrove reserve in China. Since, 1980s Chinese government has initiated a series of management program to protect mangroves from destruction. Thirty-four natural mangrove conservation areas have been established covering an area of 180 sq. km. Chinese government have taken proper reforestation program [95] and till 2002, ~27 sq. km of mangroves have been replanted with a success rate of 57% [41]. In Tanzania conservation of mangroves are carried out under Tanzania mangrove management project which contributes to direct restoration of habitats and natural regeneration [59]. Several factors responsible for the degradation of mangroves in Kenya, but due to presidential ban on harvesting of mangroves for local market from 2000 to 2010 witnessed lowest rate of mangrove degradation [58]. While no site specific factors can be attributed towards the management of mangroves in Kenya, but habitat modification and weak law and regulations can be considered a major factor of mangrove degradation [96]. In Brazil, the Forest Code describes mangrove habitats as Areas of Permanent Preservation and provides protection and restricts its use. Harvesting of mangroves and mangrove products are allowed only after receiving permission from the competent authority [97]. Cavalcanti et al. reported the worse conservation status of mangroves outside the protected area in Guanabara Bay, Brazil [98]. These areas are of two types: strict conservation and sustainable use. Conservation of mangroves in the protected area under 'sustainable use' was done by participatory management with the local community, the governmental agencies and stake holders whereas the 'strict conservation' areas only permit scientific and educational use of the resources [97]. In New Zealand, mangroves are protected under New Zealand coastal policy and for proper management and implementation of policies; an integrated estuary management system and various 'Estuary Care' groups have been established. Estuary care groups consist of community and agency members works in liaison with managing agencies for estuary and harbor management plan. The primary focus of this management plans was to justify the removal of mangroves [57]. In Australia, estuary management policies are highly diverse and variable with limited interaction between scientific and management community and between different management groups [99]. The desires for planning to conserve mangroves have been identified in different legislations and policies such as the New Zealand Coastal Policy Statement [100], the New South Wales Coastal Policy [101], the Planning Strategy for Metropolitan Adelaide [102] and the Victoria Coastal Strategy [103]. These policies demand proper implementation of better planning for conservation and management of mangroves and other estuarine habitats [57].

Strategies on mangrove managements in India

The existing mangrove management strategy is a combination of conservation through legislative policy, community awareness and sustainable exploitation of forest resources through cooperative management (Figure 2). Evidences of forest management and conservation can be traced back to British colonial regime, especially

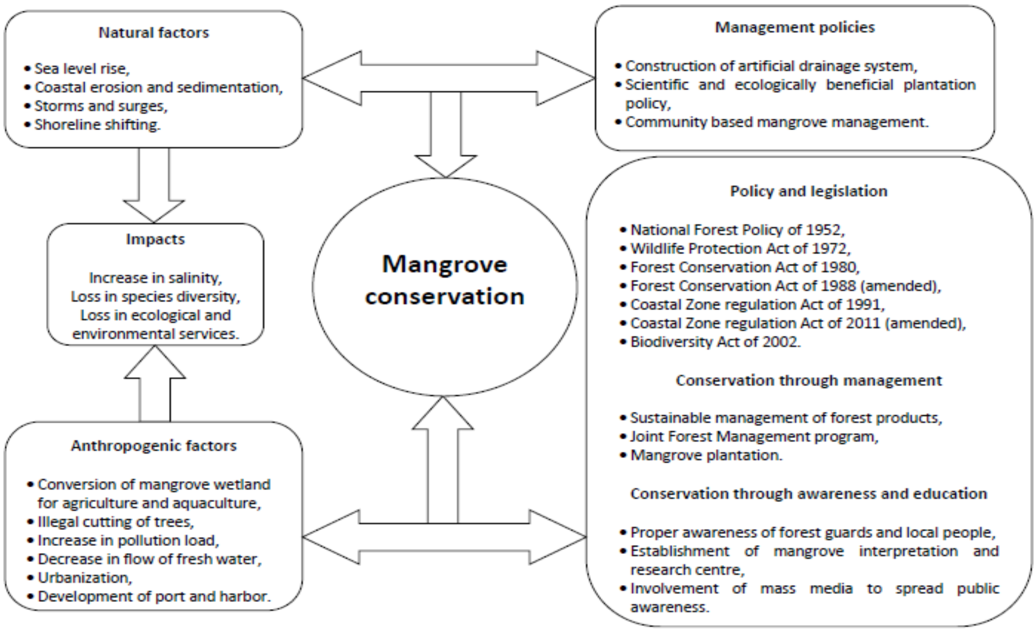

Figure 2: Mangrove conservation policies in india based on threats from natural and anthrophogenic factors.

National Forest Policy of 1894 and Forest Conservation Act of 1927. In 1952, Government of India (GoI) formulated National Forest Policy, which classified Indian forests into four classes, viz. i) Protected forests, ii) National forests, iii) Village forests and iv) Tree lands. This classification scheme has a similarity with the classification made under National Forest Policy of 1894. The policies of the government were advocated for state driven management of forests and restricting forest dwellers from practicing traditional uses of the forest. However, the policies aimed towards conservation of forests as they did not look towards forests only as a source of revenue [81]. State owned forest managements were not received much success due to limited manpower and resource vigilances to prevent illegal cutting of trees and encroachment prompting implementation of Forest Conservation Act of 1980 and its subsequent amendment in 1988 by the GoI. Forest Conservation Act of 1980 encourages reasonable use of natural forest resources while National Forest Policy of 1988 invites community participation for the regeneration and management of forest through Joint Forest Management (JFM) program. This gives rights to local inhabitants to exploit forest resources to some extent like collection of fuel wood, fodder, fish, shrimp, honey and wax and thus provided mutual benefit to community and forest department [104]. Currently, 63,618 forest protection committee vigil 22% of the forest cover [105]. Scopes to generate livelihood for local communities through mangrove regeneration at the buffer zone under JFM program were considered as an important management policy [2]. Mangrove regeneration involving local villagers have received higher success rate than afforestation program of forest department due to choice of appropriate species and planting site based on century old knowledge of local communities [106]. After Ramsar convention (1971) the legislative protection of mangroves have increased manifold, as it was strongly advocated and incorporated the need of mangrove management into National Forest Policy of India. National Mangrove Committee (NMC) as an advisory body to the GoI was formed to comprehensively manage mangroves in India. In 1987, NMC identified six major locations in east coast of India, viz. Sundarbans, Mahanadi delta, Bhitarkanika, Godavari delta, Krishna estuary and Pichavaram, to create awareness among general public through scientific and research program. The policy was to sustain mangroves through regulation along with promotional measures. Presently, almost all mangrove habitats of India enjoy legal protection under Wildlife Protection Act of 1972 and Forest Conservation Act of 1980. These acts classify forests into different classes, e.g., national park, wildlife sanctuary, reserve, protected forests and community reserve depending on their ecological value. However, laws are often amended to provide better legal protection to mangroves towards better conservation considerations. For instance, in 1973, Sundarbans was declared as a Tiger reserve, which was changed to a wildlife sanctuary in 1977 and then to a national park in 1984. Coastal Regulation Zone (CRZ) Notification of 1991 (amended in 2011) identifies mangrove habitats as an ecologically sensitive species and categorizes them as CRZ-I (i), which means that these areas required conservation of the highest order.

Strategies and Importance of Remote Sensing and GIS-Based Approach in Mangrove Managements

Despite intensive management considerations, the mangrove habitats across the globe including east coast of India are facing extreme levels of threats and vulnerabilities from land use changes and climatic variability. The major natural threats are from rising sea level, increasing coastal erosion and extreme weather events such as storm surges. Human-induced changes are conversion of mangrove habitats for aquaculture and agriculture. Population increase has a direct impact on mangrove habitats due to increase in demand for food production and industrial growth. In coming decades, sustainable conservation and management approach for the preservation of mangrove habitats will be of prime considerations. Success of sustainable management plans will depends on micro-scale management plans. Actual valuation of mangroves including their cost benefit analysis should be considered [2,107] before implementing any conservation policy. In many cases it was found that community based management of mangroves are economically beneficial but ecological issues relating to biodiversity was not considered [108]. Traditional knowledge of specific use of plants are critical to harvest natural resources, through complex century-wise understandings of the local ecosystem functions along with cultural and religious views of man-environment relationship [109,110]. The role of traditional knowledge is of great use in the management of mangrove ecosystem. Studies in India, Mexico, Philippines, Kenya, Venezuela and Tanzania documented the use of traditional knowledge in management. Hussain and Badola showed how local inhabitants of Bhitarkanika wildlife sanctuary are using their traditional knowledge to earn livelihood ~ US$ 107/household/annum [111]. Kovacs reported extensive knowledge of Mexican fisherman in explaining changes in the forest dynamics over time [112]. Walter used the knowledge of local inhabitants in mapping and explaining changes in the distribution of mangroves [91,113]. This heterogeneous spatially distributed traditional knowledge is of utmost importance to understand changes in forest dynamics [112]. Pernetta et al. reported that market values of mangrove goods and services may vary from region to region, for instance Avicennia marina propagules are used in soups in China and apparently only consumed in Indonesia [114]. In many countries mangrove propagules are regularly purchased from local villagers and forest dwellers for afforestation and conservation purposes. Geographic Information System (GIS) - based comprehensive database approach will be important for successful micro-scale management plans. Mangrove habitats are often located in an inaccessible area due to their zone of occurrences. Typical mangrove ecosystem is often inundated with tidal water. Thus field survey methods will be time consuming and expensive. The application of remote sensing will provide useful and effective real-time information [20,115-117] for detection, description, mapping and monitoring of mangrove conditions [118-121]. This will provide cost effective data over an inaccessible area [115,122,123]. A combination of remote sensing and GIS is found to be highly productive in the identification and mapping of distinct mangrove ecosystems [1,22,33,116]. For instance little changes in land use and land cover in an inaccessible region can easily be detected by remote sensing techniques. A certain diversion of flow of water due to construction of dam may accelerate the rate of erosion in a particular area and the rate of sedimentation in some other areas. These information are very crucial to design a micro-level management plan for mangrove conservation. We therefore proposed a methodology (Figure 3) for micro-scale mangrove management under the Indian context through collection and assessment of primary and secondary data together with incorporation of traditional knowledge within the GIS platform. We believe that this strategy will be of high significance for the localities which are inaccessible located in other parts of the world.

Conclusion

The study reveals that mangroves are one of the most vulnerable ecosystems in the world. They are in the verge of destruction due to continuous increase in anthropogenic stresses along the coastal areas and climatic variability. Climate change phenomenon eg. relative sea-level rise has been a lesser threat to mangroves than anthropogenic activities. Though, it may comprise a substantial proportion of predicted loss of mangroves in future. Impacts of climate vulnerabilities on mangrove ecosystems are less significant than the effects of relative sea level rise. Rise in global temperature and increased concentration of CO_2 are likely to increase productivity of mangrove wetlands, change in the timing of flowering and fruiting, and migration of mangrove species into higher latitudes. However, agriculture and shrimp farming have been identified as a major factor for mangrove destruction and thus increasing the intensity of coastal disasters. In east coast of India, mangrove wetlands are degraded due to increasing anthropogenic activities such as conversion of mangrove wetlands for aquaculture and destruction of mangrove forest for timber. The utilization and valuation of mangroves is limited to a few geographic locations such as Indian subcontinent, south-east Asia and east Africa. Reduced mangrove cover and poor health will increase vulnerabilities of human safety from increased coastal storms and surges. This predicted mangrove losses will also degrade water quality, biodiversity, eliminate fish nursery habitat, and reduces a major resource for forest dwellers that traditionally depends on mangroves for livelihood. There is a need of the better scientific approach for management of mangroves. The isolated research outcome should be compiled together to correlate knowledge regarding regional and global mangrove dynamics for proper management plan. Along with the strong legislative policies (Figure 2) special emphasis should be

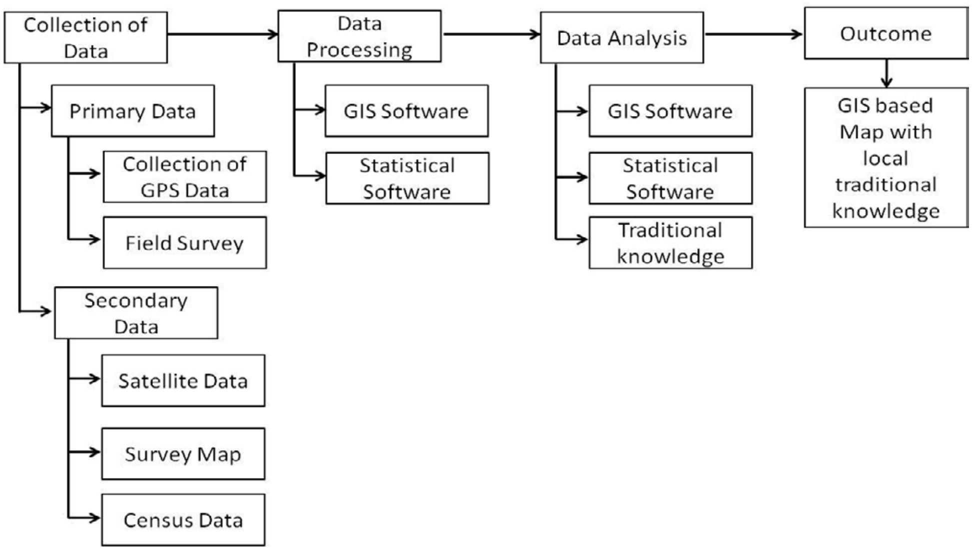

Figure 3: Proposed methodology for GIS-based micro-scale mangrove conservation and management plan for Indian mangroves.

given on community based management of mangroves. Mass media should be involved to spread awareness among forest guards and local inhabitants. Proper and efficient information on exploitation pattern of mangrove forest products in space and over time is important and its impacts on ecosystem are vital to design suitable management plan. Micro-level management strategies can be a useful tool incorporating the ground level primary and secondary information (Figure 3) and traditional knowledge related to mangrove habitat within the GIS platform. An application of remote sensing and GIS-based sustainable and comprehensive mangrove management plan is highly imperative that would benefit the environment and the society.

Acknowledgement

We are thankful to the Scientific and Engineering Research Board, Department of Science and Technology, Govt. of India for funding this research.

References

1. Satyanarayana B, Mohamad KA, Idris IF, Husain ML, Guebas FD (2011) Assessment of mangrove vegetation based on remote sensing and ground-truth measurements at Tumpat. Int J Remote Sens 32: 1635-1650.
2. Datta D, Chattopadhyay RN, Guha P (2012) Community based mangrove management: A review on status and sustainability. J Environ Manag 107: 84-95.
3. Blasco F (1984) Climatic factors and the biology of mangrove plants. UNESCO, Paris.
4. Tomlinson PB (1986) The Botany of Mangroves. Cambridge University Press, UK.
5. Gang PO, Agatsiva JL (1992) The current status of mangroves along the Kenyan coast: a case study of Mida Creek mangroves based on remote sensing. Hydrobiol 247: 29-36.
6. Tack J, Polk P (1999) The influence of tropical catchments upon the coastal zone: modelling the links between groundwater and mangrove losses in Kenya, India and Florida. The Sustainable management in tropical catchments, John Wiley and Sons Ltd, London, UK.
7. Giesen W, Wulffraat S, Zieren M, Scholten L (2007) Mangrove Guidebook for Southeast Asia. FAO Regional Officer for Asia and the pacific, Bangkok, Thailand.
8. Spalding M, Kainuma M, Collins L (2010) World Mangrove Atlas, Routledge, UK.
9. FAO Forestry (2010) Global Forest Resources Assessment. Food and Agriculture Organization of the United Nations, Rome, Italy.
10. Giri C, Ochieng E, Tieszen LL, Zhu Z, Singh A, et al. (2011) Status and distribution of mangrove forests of the world using earth observation satellite data. Blackwell Publishing Ltd, USA, Global Ecol Biogeo 20: 154-159.
11. Liang S, Zhou R, Dong SS, Shi SH (2008) Adaptation to salinity in Mangroves : Implication on the evolution of salt-tolerance. SP Sci China Press, China. Chinese Sci Bull 53: 1708-1715.
12. Alongi DM (1996) The dynamics of benthic nutrient pools and fluxes in tropical mangrove forests. J Mar Res 54: 123-148.
13. Clark MW (1998) Management implications of metal transfer pathways from a refuse tip to mangrove sediments. Sci Tot Env 222: 17-34.
14. Tam NFY, Wong YS (1999) Mangrove soils in removing pollutants from municipal wastewater of different salinities, J Environ Qual 28: 556-564.
15. Aksornkoae S, Paphavasit N, Wattayakorn G (1993) Mangroves of Thailand: Present status of conservation, use and management. International Tropical Timber Organisation, Japan International Association for Mangroves, and International Society for Mangrove Ecosystems. The economic and environment value of mangrove forests and their present state of conservation. International Society for Mangrove Ecosystems, Okinawa, Japan.
16. Guebas FD, Mathenge C, Kairo JG, Koedam N (2000) Utilization of mangrove wood products around mida creek (Kenya) amongst subsistence and commercial users. Econ Bot 54: 513-527.
17. Bandaranayake WM (1998) Traditional and medicinal uses of mangroves. J Mangroves Salt Marshes 2: 133-148.
18. Cornejo RH, Koedam N, Luna AR, Troell M, Guebas FD (2005) Remote Sensing and Ethnobotanical Assessment of the Mangrove Forest Changes in the Navachiste-San Ignacio. J Ecol Soc 10: 16.
19. Pattanaik C, Reddy CS, Dhal NK (2008) Phytomedicinal study of coastal sand dune species of Orissa. Ind J Traditional Knowl 7: 263-268.
20. Nayak S, Bahuguna A (2001) Application of remote sensing data to monitor mangroves and other coastal vegetation of India. Ind J Mar Sci 30: 195-213.
21. Ramasubramanian R, Gnanappazham L, Ravishankar T, Navamuniyammal M (2006) Mangroves of Godavari – analysis through remote sensing approach. Wetl Ecol Manag 14: 29-37.
22. Guebas FD, Hettiarachchi S, Seen DL, Batelaan O, Sooriyarachchi S, et al. (2005) Transitions in ancient inland freshwater resource management in Sri Lanka affect biota and human populations in and around coastal lagoons. Curr Biol 15: 579-586.
23. Wells S, Ravilious C, Corcoran E (2006) In the Front Line: Shoreline Protection and other Ecosystem Services from Mangroves and Coral Reefs. UNEP/ Earthprint, England.
24. Bahuguna A, Nayak S, Roy D (2008) Impact of the tsunami and earthquake of 26th December 2004 on the vital coastal ecosystems of the Andaman and Nicobar Islands assessed using RESOURCESAT AWiFS data, Int J App Earth Obs Geoinf 10: 229-237.
25. Valiela I, Bowen J, York J (2001) Mangrove forests: one of the world's threatened major tropical environments. Biosci 51: 807-815.
26. Alongi DM (2002) Present state and future of the world's mangrove forests. Environ Conserv 29: 331-349.
27. Simard M, Monroy VHR, Pineda JEM, Eda-Moya EC, Twilley RR (2008) A systematic method for 3D mapping of mangrove forests based on Shuttle Radar Topography Mission elevation data ICE sat/GLAS waveforms and field data: application to Cie´naga Grande de Santa Marta Colombia. Remote Sens Environ 112: 2131-2144.
28. Duke NC, Meynecke JO, Dittmann S, Ellison AM, Anger K et al. (2007) World without mangroves? Sci 317: 41-42.
29. Forest Survey of India (2013) State of Forest Report, Forest Survey of India, Dehradun, India.
30. Farnsworth EJ, Ellison AM (1997) The global conservation status of mangroves. Ambio 26: 328-334.
31. Gilman EL, Ellison J, Jungblat V, Lavieren HV, Wilson L et al. (2006) Adapting to Pacific Island mangrove responses to sea level rise and other climate change. Clim Res 32: 161-176.
32. Blasco F, Aizpuru M, Gers C (2001) Depletion of the mangroves of Continental Asia. Wetl Ecol Manag 9: 245-256.
33. Guebas FD, Jayatissa LP, Nitto DD, Bosire JO, Seen DL, et al. (2005) How effective were mangroves as a defence against the recent tsunami? Curr Biol 15: 443-447.
34. Field CD (1995) Impacts of expected climate change on mangroves. Hydrobiol 295: 75-81.
35. Lovelock CE, Ellison JC (2007) Vulnerability of mangroves and tidal wetlands of the Great Barrier Reef to climate change.The Great Barrier Reef Marine Park Authority, Australia.
36. Blasco F, Saenger P, Janodet E (1996) Mangroves as indicators of coastal change. Southern Cross University e-Publications, Australia.
37. Primavera JH (1997) Socio-economic impacts of shrimp culture. Aquacult Resour 28: 815-827.
38. Hamilton LS, Snedaker SC (1984) Handbook for mangrove area management. Commission on Ecology, East-West Environment and Policy Institute, Switzerland.
39. Kapetsky JM (1987) Conversion of mangroves for pond aquaculture: some short-term and long term remedies. FAO Fisheries Report Supplement, Rome 370: 129-141.
40. Osuna FP (2000) The environmental impact of shrimp aquaculture: A global perspective. Environ Pollut 112: 229-231.
41. Chen L, Wang W, Zhang Y, Lin G (2009) Recent progresses in mangrove conservation, restoration and research in China. J Plant Ecol 2: 45-54, China.

42. Lin P (1997) Mangrove Ecosystem in China, Beijing. Science Press (in Chinese) China.
43. Liu JC, Yan CL, Macnair MR (2008) Distribution and speciation of some metals in mangrove sediments from Jiulong River estuary, People's Republic of China. Bull Environ Contam Toxicol 76: 815-822.
44. Wang BS, Liao BW, Wang YJ (2002) Mangrove Forest Ecosystem and Its Sustainable Development in Shenzhen Bay. China: Science Press (in Chinese) Beijing, China.
45. Oo NW (2002) Present state and problems of mangrove management in Myanmar. Trees 16: 218-223.
46. Leimgruber P, Kelly DS, Steininger MK, Brunner J, Songer MM (2005) Forest cover change patterns in Myanmar (Burma). Environ Conserv 32: 356-364.
47. Giri C, Zhu Z, Tieszen LL, Singh A, Gillette S, et al. (2008) Mangrove forest distributions and dynamics of the tsunami-affected region of Asia. J Biogeogr 35: 519-528.
48. Webb EL, Jachowski NR, Phelps J, Friess DA, Than MM, et al. (2014) Deforestation in the Ayeyarwady Delta and the conservation implications of an internationally-engaged Myanmar. Global Environ Change 24: 321-333.
49. Ardli ER (2007) Spatial and temporal dynamics of mangrove conversion at the Segara Anakan Cilacap, Java, Indonesia. In Synopsis of ecological and socio-economic aspects of tropical coastal ecosystem with special reference to Segara Anakan, research Institute, University of Jenderal Soedirman, Purwokerto.
50. Hinrichs S, Nordhaus I, Geist SJ (2009) Status diversity and distribution patterns of mangrove vegetation in the Segara Anakan lagoon, Java. Indonesia region Environ Change 9: 275-289.
51. Brown WH, Fischer AF (1918) Philippine mangrove swamps. In Minor products of Philippine forests , Bureau of Forestry Bull. No.22, Bureau of Printing, Manila.
52. Primavera JH (2000) Development and conservation of Philippine mangroves: Institutional issues. Ecol Econ 35: 91-106.
53. Park S (2004) Aspects of Mangrove distribution and Abundance in Tauranga Harbour, Environment Bay of Plenty Environmental Publication 2004/16, Whakatane, New Zealand.
54. Evans MJ, Williams RJ (2001) Historical distribution of estuarine wetlands at Kurnell Peninsula, Botany Bay. Wetlands Aust 19: 61-71.
55. Saintilan N, Rogers K (2005) Mangrove and Saltmarsh Monitoring in Westernport Bay A Progress Report prepared by the Coastal Wetlands Unit Australian Catholic University Sydney.
56. Harty C, Cheng D (2003) Ecological assessment and strategies for the management of mangroves in Brisbane Water-Gosford. Landscape Urban Plan 62: 219-240.
57. Harty C (2009) Mangrove planning and management in New Zealand and South East Australia – A reflection on approaches. Ocean Coast Manag 52: 278-286.
58. Kirui KB, Kairo JG, Bosire J, Viergever KM, Rudra S, et al. (2013) Mapping of mangrove forest land cover change along the Kenya coastline using Landsat imagery. Ocean Coast Manag 83: 19-24.
59. Wang Y, Bonynge G, Nugranad J, Traber M, Ngusaru A, et al. (2003) Remote Sensing of Mangrove Change along the Tanzania Coast. Mar Geod 26: 35-48.
60. Iftekhar MS, Saenger P (2008) Vegetation dynamics in the Bangladesh Sundarbans mangroves: A review of forest inventories. Wetl Ecol Manag 16: 291-312.
61. Islam S, Gnauck A (2008) Mangrove wetland ecosystems in Ganges-Brahmaputra delta. Front Earth Sci China 2: 439-448.
62. 62.Roy AKD (2014) Determinants of participation of mangrove-dependent communities in mangrove conservation practices, Ocean Coast Manag 98: 70-78.
63. Kathiresan K (2000) A review of studies on Pichavaram mangrove. Hydrobiol 430: 185-205.
64. Selvam V, Gnanappazham L, Navamuniyammal M, Ravichandran KK, Karunagaran VM (2002) Atlas of Mangrove Wetlands of India (Part-1 Tamil Nadu) M.S. Swaminathan Research Foundation, Chennai.
65. Selvam V, Ravichandran KK, Gnanappazham L, Navamuniyammal M (2003) Assessment of community-based restoration of Pichavaram mangrove wetland using remote sensing data. Curr Sci 85: 794-798.
66. Chandrasekaran ES, Natarajan R (1993) Mullet seed resource of Pichavaram Mangroves, J Mar Biol Assess 35: 167-174, Southeast coast of India.
67. Muniyandi K (1986) Studies on mangroves of Pichavaram (southeast coast of India) Ph.D. Thesis, Annamalai University, Parangipettai, India.
68. Tissot C (1987) Recent evolution of mangrove vegetation in the Cauvery delta: A planological study. J Mar Biol Assess 29: 16-22.
69. Selvaraj K, Mohan VR, Jonathan MP, Srinivasalu S (2005) Modification of coastal environment: Vedaranniyam wetland, J Geol Soc Ind 66: 535-538.
70. Ponnambalam K, Chokkalingam L, Subramaniam V, Ponniah JM (2012) Mangrove distribution and morphology changes in the mullipallam creek, Int J Conserv Sci 3: 51-60.
71. Raut D, Ganesh T, Murty NVSS, Raman AV (2005) Macrobenthos of Kakinada Bay in the Godavari delta, East coast of India: comparing decadal changes, Estuar Coast Shelf Sci 62: 609-620.
72. Satyanarayana B, Raman AV, Lokman MDH, Dehairs F, Sharma VS, et al. (2009) Multivariate methods distinguishing mangrove community structure of Coringa in the Godavari delta, East coast of India. Aquat Ecos Health Manag 12: 401-408.
73. Satapathy DR, Krupadam RJ, Pawan Kumar L, Wate SR (2007) The application of satellite data for the quantification of mangrove loss and coastal management in the Godavari estuary. Environ Monitor Assess 134: 453-469.
74. Gamage N, Smakhtin V (2009) Do river deltas in east India retreat? A case of the Krishna Delta. Geomorphol 103: 533–540.
75. Ravishankar T, Navamuniyammal M, Gnanappazham L, Nayak SS, Mahapatra GC, et al. (2004) Atlas of Mangrove Wetlands of India (Part - 3 Orissa) M.S. Swaminathan Research Foundation, Chennai.
76. Pattanaik C, Prasad N (2011) Assessment of aquaculture impact on mangroves of Mahanadi delta, East coast of India using remote sensing and GIS, Ocean Coast Manag 54: 789-795.
77. Reddy CS, Pattanaik C, Muthy MSR (2007) Assessment and monitoring of mangroves of Bhitarkanika wildlife sanctuary, using remote sensing and GIS, Curr Sci 92: 1409-1415.
78. Chaudhuri AB, Choudhury AC (1994) Mangroves of the Sundarbans, vol 1: India. IUCN, Bangkok, Thailand.
79. Canonizado JA, Hossain MA (1998) Integrated forest management plan for the Sundarbans Reserved Forest (Final Draft). Mandala Agricultural Development Corporation and Forest Department, Ministry of Environment and Forest, Bangladesh.
80. Gopal B, Chauhan M (2006) Biodiversity and its conservation in the Sundarban Mangrove Ecosystem. Aqua Sci 68: 338-354.
81. Dasgupta R, Shaw R (2013) Changing perspectives of mangrove management in India - An analytical overview. Ocean Coast Manag 80: 107-118.
82. Eriscson JP, Vörösmarty CJ, Dingman SL, Ward LG, Meybeck M (2006) Effective sea-level rise and deltas: Causes of change and human dimension implications, Global Planet Change 50: 63-82.
83. SMRC (2003) The vulnerability assessment of the SAARC coastal region due to sea level rise: Bangladesh Case, SMRC-No. 3, SMRC Publication, Dhaka, Bangladesh.
84. Alam MJB, Ahmed F (2010) Modeling climate change: Perspective and application in the context of Bangladesh. In: Indian Ocean Tropical Cyclone and Climate Change, [edn] Charabi Y, Springer Netherlands 15-23.
85. Krishnamurty K (1990) The apiary of the mangroves. In Wetland Ecology and Management: Case Studies, eds. Whigham DF, Dykyjova D, Kluwer SH Academic Publishers, Dordrecht, The Netherlands.
86. Richards JF (1990) Agricultural impacts in tropical wetlands: Rice paddies for mangroves in south and southeast Asia. In Wetlands: A Threatened Landscape. Basil Blackwell, Oxford.
87. Badola R, Barthwal S, Hussain SA (2012) Attitudes of local communities towards conservation of mangrove forests: A case study from the east coast of India, Estuar Coast Shelf Sci 96: 188-196.

88. Soegiarto A (1984) The mangrove ecosystem in Indonesia, its problems and management. In: Physiology and management of mangroves, Dr Junk W Publishers, The Hague.

89. Primavera JH, Esteban JMA (2008) A review of mangrove rehabilitation in the Philippines: successes, failures and future prospects, Wetlands Ecol Manage 16: 345-358.

90. National Mangrove Committee (1987) Philippines Case Study: Mangroves of Asia and the Pacific: status and management. Tech Rep UNDP/UNESCO Research and Training Pilot Programme on Mangrove Ecosystems in Asia and the Pacific (RAS/79/002) Natural resources.

91. Walters BB (2003) People and mangroves in the Philippines: Fifty years of coastal environmental change, Environ Conserv 30: 293-303.

92. Li JC (2008) Environmental Impact Assessments in Developing Countries: An Opportunity for Greater Environmental Security? Working Paper No. 4, United States Agency for International Development (USAID) and Foundation of Environmental Security and Sustainability (FESS).

93. Burma Environmental Working Group (2011) Burma's Environment: People, Problems, Policies. Wanida Press, Chiang Mai.

94. Rao M, Rabinowitz A, Khaing ST (2002) Status review of the protected-area system in Myanmar, with recommendations for conservation planning. Conserv Biol 16: 360-368.

95. Zheng DZ, Li M, Zheng SF, Liao B, Chen Y (2003) Headway of study on mangrove recovery and development in China, Sci Technol Guangdong Prov 19: 10-14.

96. UNEP (2009) Transboundary Diagnostic Analysis of Land-based Sources and Activities Affecting the Western Indian Ocean Coastal and Marine environment, UNEP, Nairobi, Kenya.

97. Magris RA, Barreto R (2010) Mapping and assessment of protection of mangrove habitats in Brazil. Pan-American J Aqua Sci 5: 546-556.

98. Cavalcante RM, Sousa FW, Nascimento RF, Silveira ER, Freire GSS (2009) The impact of urbanization on tropical mangroves (Fortaleza, Brazil): Evidence from PAH distribution in sediments, J Environ Manag 91: 328-335.

99. Smith TF, Sant M, Thom B (2001) Australian estuaries: A framework for management. Indooroopilly, Queensland: Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management.

100. New Zealand Government (1994) New Zealand Coastal Policy Statement. Wellington: Department of Conservation.

101. New South Wales Government (1997) NSW Coastal Policy–A sustainable future for the New South Wales Coast, Sydney.

102. South Australian Government (2006) Planning Strategy for Metropolitan Adelaide, Adelaide.

103. Victorian Coastal Council (2008) Victorian Coastal Strategy, Melbourne.

104. Singh A, Bhattacharya P, Vyas P, Roy S (2010) Contribution of NTFPs in the livelihood of mangrove forest dwellers of Sundarban, J Hum Ecol 29: 191-200.

105. Balooni K (2002) Participatory Forest Management in India-An Analysis of Policy Trends amid 'Management Change', Policy Trend Report.

106. Sarvanan KR (2005) A Study on the Biodiversity and Management of Pondicherry Mangroves. Department of Science, Technology and Environment, Government of Pondicherry, India.

107. Lewis RR (2005) Ecological engineering for successful management and restoration of mangrove forests. Ecol Eng 24: 403-418.

108. Walters BB (2004) Local management of mangrove forests in the Philippines: Successful conservation or efficient resource exploitation? Hum Ecol 32: 177-195.

109. Davis A, Wagner JR (2003) Who knows? On the importance of identifying "experts" when researching local ecological knowledge. Hum Ecol 31:463-489.

110. Walters BB, Ronnback PP, Kovacs JM, Crona B, Hussain SA, et al. (2008) Ethnobiology, socio-economics and management of mangrove forests: A review. Aqua Bot 89: 220-236.

111. Hussain SA, Badola R (2010) Valuing mangrove benefits: contribution of mangrove forests to local livelihoods in Bhitarkanika Conservation Area. Wetl Ecol Manag 18: 321-331.

112. Kovacs JM (2000) Perceptions of environmental change in a tropical coastal wetland, Land Degradr Dev 11: 209-220.

113. Walters BB (2005) Ecological effects of small-scale cutting of Philippine mangrove forests. Ecol Manag 206: 331-348.

114. Pernetta JC, Ong JE, Padilla NEO, Rahim KA, Chinh NT (2013) Determining regionally applicable economic values for coastal habitats and their use in evaluating the cost effectiveness of regional conservation actions: the example of mangroves. Ocean Coast Manag 85: 177-185.

115. Green EP, Mumby PJ, Edwards AJ, Clark CD (1996) A review of remote sensing for tropical coastal resources assessment and management. Coast Manag 24: 1-40.

116. Filho PWMS, Fariasmartins EDS, Costa FRD (2006) Using mangroves as a geological indicator of coastal changes in the Braganca macrotidal flat, Brazilian Amazon: A remote sensing data approach. Ocean Coast Manag 49: 462-475.

117. Chauhan HB, Dwivedi RM (2008) Inter sensor comparison between RESOURCESAT LISS III, LISS IV and AWiFS with reference to coastal landuse/landcover studies. Int J App Earth Obs Geoinf 10: 181-185.

118. Green EP, Clark CD, Edwards AJ (2000) Image classification and habitat mapping. In Remote Sensing Handbook for Tropical Coastal Management. [edn]. Edwards AJ, Paris: UNESCO, Paris.

119. Kovacs JM, Wang J, Correa MB (2001) Mapping Disturbances in a Mangrove Forest Using Multi-date Landsat TM Imagery. Environ Manag 27: 763-776.

120. Seto KC, Fragkias M (2007) Mangrove conversion and aquaculture development in Vietnam: A remote sensing-based approach for evaluating the Ramsar Convention on Wetlands. Global Environ Chang 17: 486-500.

121. Kuenzer C, Bluemel A, Gebhardt G, Quoc TV, Dech S (2011) Remote sensing of mangrove ecosystems: a review. Remote Sens 3: 878-928.

122. Everitt JH, Escobar DE, Judd FW (1991) Evaluation of airborne video imagery for distinguishing black mangrove (Avicennia germinans) on the lower Texas Gulf coast. J Coast Res 7: 1169-1173.

123. Mumby PJ, Green EP, Edwards AJ, Clark CD (1999) The cost-effectiveness of remote sensing for tropical coastal resources assessment and management. J Environ Manag 55: 157-166.