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

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Abstract

Mangroves are one of the most threatened ecosystems worldwide located within the intertidal zones of tropics and subtropics. They provide both ecological 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., Hibicicus tilisaeceus, 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,

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 reclamations [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.), while other species like Rhizophora mucronata, Rhizophora apiculata and Excoecaria agallocha 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 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].

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 decrease in mangrove species [64]. The wetland is characterized by the presence of eight mangrove species, among them Avicennia officinalis, A. marina, Sonneratia alba, Rhizophora apiculata, Excoecaria 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.

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 to 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 Jagir 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, Excoecaria 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 Excoecaria agallocha, Heritiera littoralis, Avicennia officinalis and Cynometra rhamiflora 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. Rddy 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 caseolaris 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 Fomes and Avicennia marina for boat making, poles and rafters). They 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., Bangladesh 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 managed under ‘sustainable use’ of Permanent Preservation and provides protection and restricts its use of mangroves in the protected area under ‘sustainable use’ was done by 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 has 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 of mangroves in the protected area under ‘sustainable use’ was done by 2000 and 2010 witnessed lowest rate of mangrove degradation [58]. While no site specific factors can be attributed towards the management of mangroves in Brazil [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
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 uses 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 be easily 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 CO₂ 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.](image)
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.

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References


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


