Chapter 8
A Systematic Review on the Impact of Urbanization and Industrialization on Indian Coastal Mangrove Ecosystem

Deepika Sharma, Karuna Rao, and AL. Ramanathan

Abstract The history of human civilization has witnessed a strong and rapid transformation pattern in the coastal environment. It harbors a prominent transition zone of land and sea that plays a significant part in the socioeconomic and environmental aspects. Due to tremendous pressure from anthropogenic perturbations manifested by coastal squeeze, it's protection and conservation become substantial. 5.04% of the mangrove land has been converted to aquaculture land between 1988 and 2013. Present mangrove loss is 35% which is supposed to reach 60% by 2030. Human activities increase the chances of exposure of coastal waters to effluents (organic and inorganic) released from the industrial and urban components which accelerate the metals and nutrient pollution, eutrophication, and oxygen depletion. This tends to alter ecosystem dynamics and biogeochemical processes with serious impacts on the biota. Pichavaram shows an increase in nitrate from 5.9 mg/l in 1995 to 29.9 mg/l in 2006–2007. In Sundarbans it increases from 1.14 mg/l in 2001 to 3.69 mg/l in 2006 and in Godavari from 0.61 mg/l in 2001 to 2.25 mg/l in 2016. The phosphate values increase from 0.28 mg/l in 1995 to 6.6 mg/l in 2006 in Pichavaram mangroves. Manori creek, Mumbai, shows hike in phosphate in past 25 years. The value increases from 0.06 mg/l in 1982 to 2.19 mg/l in 2007. A consistent increase in heavy metal content has been observed in Sundarban, Pichavaram, and Goa mangroves. Thus, the resultant surge of heavy metals and nutrient pollutants indicates growth of fallow land, agricultural, and aquaculture activities and industrial pollution. This chapter has been constructed to discuss a holistic view of the major drivers of coastal mangrove ecosystem degradation by reviewing the case studies to highlight the past changes and present trends of human activities through industrialization and urbanization. We evaluate the impact of these human influences on the mangrove ecosystem, with an approach to emphasize the crucial role of mangroves, both in terms of quality and quantity, and the absolute need to conserve their future.

Keywords Mangrove · Coastal ecosystem · Anthropogenic perturbation · Pollution status · Biogeochemical processes

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Abbreviations

µM	Micromolar
ADB	Asian Development Bank
As	Arsenic
BOD	Biochemical oxygen demand
cal/g	Calorie per gram
Cd	Cadmium
COD	Chemical oxygen demand
Cr	Chromium
CRZ	Coastal Regulation Zone
Cu	Copper
DAP	Diammonium phosphate
DIP	Dissolved inorganic phosphate
DO	Dissolved oxygen
E	East
EDC	Endocrine disrupter compounds (EDCs)
FAO	Food and Agricultural Organization
Fe	Iron
FSI	Forest Survey of India
GIS	Geographic Information System
ha	Hectare
JMM	Joint Mangrove Management
km^2	Square kilometer
MAP	Management Action Plan
mg/kg	Milligram per kilogram
mg/l	Milligram per liter
MMR	Mumbai Metropolitan Region
Mn	Manganese
MSL	Mean sea level
N	Nitrogen
N	North
NACA	Network of Aquaculture Centres in Asia-Pacific
NGO	Nongovernmental organization
Ni	Nickel
NOAA	National Oceanic and Atmospheric Administration
P	Phosphorus
PAH	Polycyclic aromatic hydrocarbons
Pb	Lead
POP	Persistent organic pollutants (POPs)
PPCP	Pharmaceuticals and personal care products
ppm	Parts per million
ppmv	Parts per million by volume
S	South
SEZ	Special Economic Zone

Si	Silicon
SPM	Suspended particulate matter
TSS	Total suspended solid
W	West
Zn	Zinc

1 Introduction

Mangroves are the intertidal forest ecosystems that dominate 75% of the world's shoreline (Ranjan et al. 2008) between 25° N and 25° S with a projected area of 1.7 to 2.0 × 10^5 km^2 (Borges 2003). These woody halophytes occupy severe place exposed to whims of both land-dwelling and the oceanic, hit by prevailing heavy rain and storm, with high salinities and droughts, shifting sediments, inundation, and exposure. But this unbending nature to colonize provides many rewards too. Mangrove ecosystems have some benefits over other ecosystems which include adaptations like aerial breathing roots called "pneumatophores," succulent leaves, sunken stomata, vivipary, stilt roots, and buttresses that are mainly exhibited by these salt-tolerant plant community. The crustaceans and fish move in with every tidal inflow to feed in the spaces that are shared by the insects and birds as well. The interaction of the species adds up to the rich diversity observed in these nooks, hence providing significant grounds for nursery and sites for breeding (Spalding 2010). These structures are the basis of renewable logs, locations for sediment accumulation, impurities, carbon, and nutrients which also guard against coastal erosion (Alongi 2002). These myriad patches act as major channels for the exchange of tides of dissolved and particulate matter as well as organic matter exportation and nutrients to the ocean, caused majorly by biological and physical processes within the forest ecosystem (Singh et al. 2005). Hence mangrove ecosystems play an important role in the biogeochemical cycling of these materials. However, the Earth's ecosystems have always been subjected to a persistent change through which the organisms tend to respond and adapt, thereby adjusting to climate change and other physical attributes. The biological and ecological alterations in the ecosystems are the result of both disturbances created by nature and man-made factors that can change in their period, occurrence, magnitude, and power and facilitate adaptive changes (Alongi 2008). Mangrove forests, like other ecosystems, face similar disorders which can change in their fundamental nature in time and space. Bridging the gap in the terrestrial and marine over small latitudes, they are true ecotones that fuse the components of both sea and land biomes, along with the development of unique structural and functional adaptations (Alongi 2012).

The objective of this chapter is to critically assess the impact of urbanization and industrialization on the coastal mangrove ecosystem. It deals with an approach to emphasize the crucial role of mangroves, both in terms of quality and quantity with the absolute need to conserve their future.

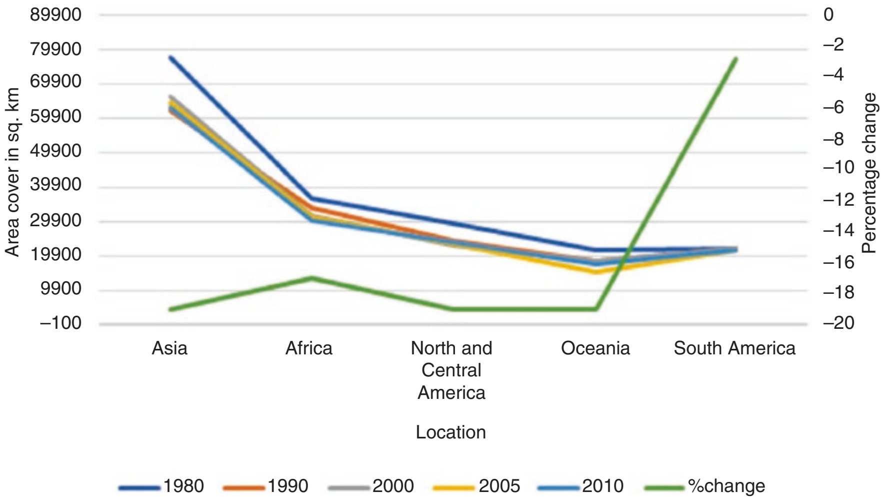

Fig. 8.1 Percentage change in the global mangrove area cover over the years around the globe. (Source: Gurjar et al. 2019)

1.1 Global Mangrove Cover

The distribution of mangroves in over 123 countries and territories makes up 15.2 million ha of the total world mangrove cover which is less than 1% of the tropical forests of the world and less than 0.4 % of the total global forest domain. The largest share of mangroves occurs in Asia where around 33.5% is found in Southeast Asia and 6.8 % in South Asia. The regions of North Central America and South America followed by West and Central Asia anchor the rest of the mangrove cover. India holds 45.8% of the total South Asian mangrove cover. Figure 8.1 shows the percentage changes in the global mangrove cover by the Food and Agricultural Organization (FAO) of the United Nations which shows a decrease of about 18% in global mangrove cover. It is observed that there is a decrease in mangrove cover of Asia, Oceania, and North and Central America by 19%, while the mangroves of South America remain relatively unchanged and show a minor decrease of 2.8%. Further it is noticed that the mangrove cover of Africa decreases by 17% Food and Agricultural Organization (FAO 2010).

1.2 Indian Coastal Mangrove Systems

Sheltering the widespread and diverse mangrove wetlands, the estuaries, and the "coasts of nine maritime states and four union territories" of the Indian peninsula, bounded by the western Arabian sea, southern Indian Ocean, and the Bay of Bengal on the east, it runs over a distance of 7516.6 km including the coastline of Lakshadweep islands and Andaman and Nicobar Islands along with the mainland. Therefore, three major classifications of the mangrove habitat arise as "deltaic (Eastern coast mangroves); estuarine and backwater (Western coast Mangroves), and Insular (Andaman and Nicobar Islands)" (George et al. 2019). The species which dominate the Indian mangrove ecosystems are *Rhizophora mucronata*, *Sonneratia alba*, *Avicennia alba*, *Avicennia officinalis*, *Morinda citrifolia*, *Heritiera littoralis*, *Phoenix paludosa*, *Ceriops tagal*, and *Bruguiera cylindrica*. According to Forest Survey of India (FSI), State of Forest Report, Dehra Dun, 1999, the majority of mangrove wetlands (487,100 ha) in India occurs on the east coast, which is nearly 56.7% (275,800 ha) and 23.5% (114,700 ha) along the west coast, while Andaman and Nicobar Islands accommodate the remaining 19.8%. Figure 8.2 here depicts a map showing the major mangrove forest locations in India. There is a difference in the geomorphic settings of the

Fig. 8.2 Map locating the mangrove forest in India. (Source: http://www.casmbenvis.nic.in/database/Mangroves_3893.aspx?format=Print)

mangrove wetlands of the east coast and the west of the Indian coast. On the western coast of India, mangrove wetlands are smaller in size, lesser in diversity, and lesser complicated in terms of tidal creek network which is due to the coastal zone being "narrow and steep in slope due to the presence of Western Ghats" with the absence of major west-flowing river. However, east onwards, the mangrove wetlands are larger (~90% of the total mangroves forest cover for the whole country) and comprise higher diversity, and water bodies connected with mangroves are delineated by the occurrence of larger brackish water bodies and an intricate network of tidal creeks and canals. The greater delta created by the presence of east-flowing rivers and the gentle slope of the coast are the two features that contribute to abundance (Selvam 2003).

Sundarbans (West Bengal): The Sundarbans mangrove forests, the world's largest coastal wetland, are found in the delta created by the rivers Ganga, Brahmaputra, and Meghana, with a cover of about 1 million ha; the forests get 60% shared with Bangladesh and 40% lie within India. They are found on the upper side of the Bay of Bengal between 21°40′ N and 22°40′ N latitude and 88°03′ E and 89°07′ E longitude. They are influenced by the enormous amounts of sediments carried by the rivers which lead to the expansion and nutrient dynamics along with the impact of subtropical monsoon climate (annual rainfall: 1600–1800 mm) and extreme cyclonic events (Gopal and Chauhan 2006; Prasad et al. 2017). This mangrove estuary has large tidal flats which is a common characteristic in mangrove estuaries dominated by tides and suitable microenvironment. Microenvironments are provided for mangrove plant colonization, which produces communities of dense and tall mangrove plants.

Bhitarkanika (Odisha): The "second largest" Indian mangrove ecosystem comprises the mangrove forests, estuary, creeks, rivers, backwater, accreted land, and mudflats, flourishing the delta region of "Brahmani and Baitarani rivers." Geographically this ecosystem is located in the Kendrapara district of Orissa between 20°4′–20°8′ N latitudes and 86°45′–87°50′ E longitudes. It has been declared as a Wildlife Sanctuary covering an estimated area of 672 km^2 in 1975. It is a tide-dominated mangrove with a mean tide level of 1.5–3.4 m that consists of widespread low gradient intertidal zones available for colonization of mangroves supporting a rich floral diversity (Chauhan and Ramanathan 2008).

Coringa and Gaderu (Andhra Pradesh): Located in Andhra Pradesh between 16°51′–17°00′ N latitudes and 82°14′–82°22′ N longitude, it occurs over the delta formed by the second largest river in India, Godavari, that before discharging into the Bay of Bengal southwest of Visakhapatnam branches into Vasishta Godavari and Gautami Godavari. The region between Kakinada Bay and Gautami Godavari is characterized by condensed vegetation and that belongs to Coringa wildlife sanctuary (Dehairs et al. 2000).

Pichavaram (Tamil Nadu): Situated between the estuaries of Vellar and Coleroon (Lat. 11°2′; Long. 79°47′ E), the forest occupies 51 islets that range from 10 m^2 to 2 km^2, covering an area of about 1100 ha, which are characterized by complicated waterways' separation, that connect the Coleroon and Vellar estuaries. The southern region near the Coleroon estuary is dominated by mangrove vegetation, while the northern part that resides close to the Vellar estuary is characterized by maximum mudflats. This region is influenced by three types of waters that include neritic water (Bay of Bengal), brackish water (Vellar and Coleroon estuaries), and freshwater (irrigation channel as well as the main channel of Coleroon river). The majority of the area is covered by the forest, i.e., 50% and 40% by the waterways out of which remains for the sand-flats and mudflats (Kathiresan 2000).

Kerala mangroves: The mangrove vegetation occupies the estuarine water body banks and as narrow continuous belt or patches, adjacent to the backwater channels (Lat. 9°28′ and 10°10′ N; Long. 76°13′ E). They are influenced by the tidal flooding and 41 perennial rivers that supply fresh water to create an extensive expansion of fringing mangroves of backwaters, estuaries, and creeks. The major districts with the mangroves are Kannur and Kasaragod followed by Kollam, Trivandrum, Alappuzha, Kottayam, Thrissur, Ernakulam, Kozhikode, and Malappuram along with the three Ramsar sites, namely, Ashtami, Sasthamkotta, and Vembanad (George et al. 2019).

Goa mangroves: They are located (Lat. 14°53′–15°48′ N; Long. 73°40′–74°20′ E) along with Mandovi-Zuari estuary complex with an area of 12,000 ha on the central west coast of India (Attri and Kerkar 2011).

Mumbai mangroves (Maharashtra): The coastline of Mumbai is cushioned by a mangrove cover of 66 sq. km (Lat. 18°55′–19°20′ N; Long. 72°45′–73°00′ E) with its extensive network of creeks fringed with mangroves along both the banks.

Gulf of Kachchh mangrove (Gujarat): The state of Gujarat has four regions of mangrove cover, i.e., Kachchh, Gulf of Kachchh, Saurashtra, and South Gujarat that constitute the mangrove coastline (1048 km^2) (Pandey and Pandey 2013). Twenty percent of the total area is occupied by the dense vegetation, and the remaining area is constituted by degraded mangroves and saline-encrusted mudflats.

Andaman and Nicobar mangrove: It contributes 13% of the entire Indian mangrove area where the diversity is found to be similar to the Southeast Asian mangroves. They are recognized to be best in terms of density and growth in the country with a relative mangrove density of 76.5% (Goutham-Bharathi et al. 2014). It is located in an extensive group of 572 islands (8249 km^2) that lie in the Bay of Bengal (Lat. 6°45′–13°41′ N; Long. 92°12′–93°57′ E) on the eastern side of India. The mangroves originate along tidal creeks, bays, and lagoons where the creeks form the outlets to the rain-fed streams that bring silt from the interior to the shore for the formation of muddy plains facilitating the spread and regeneration of mangroves (Selvam 2003).

1.3 Threat to Mangrove Ecosystems

Despite their ecological and economic importance, the mangroves are still facing destruction, majorly related to the density of the human population. The degradation and devastation of mangrove ecosystems come under both natural and anthropogenic influences.

- Forest clearing
- Overharvesting
- River changes
- Overfishing
- Pollution
- Climate change

The key explanations for devastation can be depicted through urbanization, industrialization, shrimp aquaculture, mining activity, and overexploitation of resources like wood and fisheries. The restoration and rehabilitation projects are increasing all over the world with few country areas showing an increase in mangrove area. Till 2025, the exploitation is expected to continue unless they are valued for the services they provide in a sustainable manner with their greatest future hope in reduced human population growth (Alongi 2002).

1.3.1 Natural Influences

The impact of natural factors on the structure and function of the mangrove coastal ecosystem can be seen on the spatial and temporal scales. Natural disturbances such as cyclones and other storms, lightning, tsunami, and floods adversely affect the mangroves. On the Indian coast, recurrent tropical cyclones, storms, and tsunamis have damaged the mangrove forests. For example, during 1999 in Odisha, a major super cyclone devastated a large area of mangroves with an estimated loss from 307.66 to 179 km^2. Similarly, loss of mangrove forest was observed during the tsunami in 2004 in the south coast and Andaman and Nicobar Islands (Suresh and Sahu 2015). After 1999, the most devastating tropical storm reported in the region was the Amphan cyclone which impacted the Sundarbans, Bengal's first line of defense from the violent storms that periodically arise in the Bay of Bengal (Sen 2020). Other natural factors include pests and invasive species which show a severe impact on the mangrove forest. Twenty percent of a species, *Heritiera fomes*, of the trees have been harshly affected by the "top dying" disease in the Sundarbans of Bangladesh.

1.3.2 Anthropogenic Influences

Anthropogenic activities include not only the activities done to meet the food, clothing, housing, and energy, but they also include the developmental activities like dam construction, mining, etc. where these human activities affect the mangrove ecosystem directly as well as indirectly. Previously, the flawed picture of mangroves being categorized as "waste lands" led to their conversion to agricultural, industrial, and residential uses (Hema and Devi 2015). The major impacts of the human influence on the coastal mangrove ecosystem are given below.

Agricultural Activities

Farming has affected a large fraction of the mangrove forest in India which aligns with the two main causes of this decline, i.e., destruction of the habitat and its alteration. The expansion in agriculture during the past 100 years in India and Bangladesh has destroyed an estimated area of 150,000 ha of mangroves (Dhargalkar et al. 2014). In the states of Goa, Karnataka, and Andhra Pradesh, plantations of coconut and paddy are commonly carried out. The salinity of the soil is reduced using rainwater after destroying the mangrove patches. Further, these areas are protected from soil water intrusion by forming embankments which makes these areas suitable for plantation.

Industrial Development

One of the victims of rapid industrial development are the mangrove belts present across those regions. The escalated industrialization and its uncontrolled pressure has increased in the last few decades. The industrial waste discharge introduces heavy metals to the system that remains the major reason to impact the health of mangroves of a region. These virgin mangroves receive various chemical contaminants like heavy metals, inorganic nutrients, organic contaminants, hydrocarbons, etc., from the effluents of the industries (Maiti and Chowdhury 2013). When heavy metals are introduced, the mangroves absorb them mainly through roots and transport a part upward into the sensitive tissues; therefore, the concentration of heavy metals is found to be more in the roots than in the shoots. This introduction can cause changes in metabolic activities, cell structure, and plant growth (He et al. 2014). A study was done on seven different estuarine regions on the South Gujarat coast consisting of seven different rivers: Ambica, Purna, Par, Varoli, Damanganga, Kolak, and Auranga. It revealed the accumulation of eight different heavy metals, Pb, Ni, Cr, Cd, Zn, Cu, Fe, and Hg, in the mangrove plant tissues as well as mangrove sediments from the surrounding industrial areas. Here the industries majorly include manufacturing and engineering, papers, dyes, textiles, chemicals and petrochemicals, pharmaceuticals, shipbuilding, diamond processing, etc. Another coastal region which resides along the Bay of Bengal, Visakhapatnam, here the sum up of decades of industrialization and urban development projects along the wetlands of Meghadrigedda creek has reduced the extent of 400 acres to less than 40. The richness of the ecosystem and home to many birds and endangered species has been doomed with the drastic beach erosion (The Hindu, 2020). Further, the mangroves of Mumbai region are also impacted by the resultant of around 9000 industries of chemicals, fertilizers, iron and steel, oil refineries, and thermal power which give a huge output of emissions of gas, solid and liquid wastes, and toxic and hazardous wastes, thus resulting in the degradation. The wastes are being discarded into the creeks which leads to the deterioration of water quality with heavy siltation (Harun et al. 2015). These recent industrial and domestic activities have transformed the once lush flourishing mangrove areas. With great fisheries and oyster beds, Mahim bay and Thane creek were affected with high concentration polluted areas that led to nonexistent fisheries and lower dissolved oxygen. These important areas for the spawning of fishes and other marine flora and fauna have been impacted due to the anthropogenic construction and mixing of effluents. As reported by a local fisherman, instead of fish, the grounds are being occupied by the multiplying mosquitoes.

Heavy Metals

Heavy metals occur naturally in the environment, but due to interference of human activities, their background concentration has increased dramatically. They come under the category of serious pollutants as they are nonbiodegradable and remain persistent for years. The source of heavy metals is rivers, and they make their way to coastal and mangrove environments. Other sources include rainfall, tidal activities, and land runoff (Nriagu and Pacyna 1998). Upon entering the coastal ecosystem, they get absorbed by the sediments by the processes like co-precipitation and adsorption on the solid particles (Santschi et al. 1990). After some time these adsorbed metals become remobilized and available to the water column when the soil gets saturated or when there is a change in the environmental conditions (Tam and Wong 1993).

A case study on the Sundarbans upon the occurrence of elevated levels of heavy metals in India and Bangladesh wetlands has been done. Trace metals like As, Cd, Co, Cu, Fe, and Ni show an increase from 2004 to 2012 as shown in Table 8.1. A consistent increase in Cu, Ni, and Zn has been observed in Goa mangroves from 2011 to 2016. High values of heavy metals in Pichavaram sediments, then other mangroves, might be due to the higher presence of trace metals in the Vellar and Coleroon rivers and display anthropogenic influence through domestic sewage and agricultural runoff (Ramanathan et al. 1999). These two rivers pass through the densely populated industrial city along with the addition of fertilizers, pesticides, and heavy metals from the upstream region (Prasad 2012). By analyzing the course of industrial influence that has shaped up the mangroves towards new adaptations, a long-term sustainable functioning of the estuarine ecosystem can be deduced by introducing the tolerant species that can help in sustaining high heavy metal content in the sediments. While in Pichavaram, tsunamigenic sediments show the highest trace metal concentration (R. K. Ranjan et al. 2008) for all the trace metals which might be due to higher discharge of wastewater at that time along with the tsunami-driven sediments derived from the deep sea. The heavy metals like Cu, Cd, Pb, and Zn have anthropogenic origin, for example, they are derived from the untreated wastewater discharge from several industries located on the coastal shorelines. Runoff from agriculture, sewage, and other effluents are other anthropogenic sources.

The concentration of metal in sediment can sometimes depend on the variation in the geography for the same trace metal. The studies have suggested the effect of

Table 8.1 Trace metal concentration in the mangrove ecosystems of Goa, Pichavaram, and Sundarbans (Ranjan et al. 2017)

Site	Year	As (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Mn (%)	Ni (ppm)	Pb (ppm)	Zn (ppm)
Goa	2011			34.36	17.32	45.34	12.18	0.16	–	22.51	72.853
Goa	2015			22.85	271.18	36.26	14.53	0.512	47.15	–	104.34
Goa	2016			114.35	–	64.99	8.72	0.25	118.565	–	277.9
Pichavaram	1999		6.6	35.3	141.2	43.4	3.25	0.09	62	11.2	93
Pichavaram	2008		34.74	–	6200	132.3	2.5	0.08	252.1	–	106
Pichavaram	2013		23	–	152	34	3.8	0.033	51	21	16
Sundarbans	2004	3.5	0.1	12.46	36.44	35.47	3.08	0.14	33.46	17.2	74.18
Sundarbans	2008	–	–	–	–	90.75	–	–	–	38.175	303.75
Sundarbans	2009	8.3	0.15	10.41	55.98	25.74	3.12	0.58	30.17	65.59	22.8
Sundarbans	2010	8.09	0.18	–	99.01	28.94	–	–	51.86	23.01	–
Sundarbans	2012	–	1.88	23.48	44.13	38.47	3.75	0.0574	50.35	30.28	75.87
Sundarbans	2015	3.82	0.21	7.67	28.3	38.29	0.29	0.06	34.5	15.8	34.42

pollution on the plants with the use of response of biological phenomena like endurance, production of biomass, defoliation, photosynthetic effects, metallothionein expression, and enzymes. At the coast of Bhitarkanika, an investigation revealed a mangrove species, *A. officinalis*, accumulates the highest concentration of Fe, Cu, Mn, and Zn among other species, namely, *Xylocarpus granatum*, *Bruguiera cylindrica*, *Rhizophora mucronata*, and *Ceriops decandra.* Most investigations have revealed the *Avicennia* sp. has the highest tolerance in respect of heavy metals among mangroves and similarly in India, *A. marina*, in different mangrove patches. These studies show the importance of mangroves in sequestering heavy metal pollutants. Destruction and degradation of mangroves will lead to the loss of plant species and subsequently their potential to store heavy metals; hence, the restoration and management of the mangrove ecosystem are necessary. More pollution will lead to more proliferating pollution-tolerant mangroves which will lead to replacing other species and, hence, would result in deterioration of mangrove biodiversity.

Nutrients

Mangrove areas are highly productive forests which are rich in carbon but poor in nutrients. Some studies were done revealing mangroves maintaining high productivity despite facing nutrient limitation (Reef et al. 2010). This is possible only when the nutrients limit growth via processes like nutrient cycling and nutrient retention mechanisms (Ball 1988). Mangroves are benefitted from their location between land and sea and hence are generally not limited to the elements like magnesium, sulfur, boron, sodium, and potassium, but they are frequently limited by the nutrients like nitrate and phosphate. Fertilization studies (Lovelock et al. 2006) reveal that nutrient limitation of either nitrate or phosphate or both depends on several factors. These factors include the amount of terrigenous input, species composition, texture and fertility of the soil, redox status of soil, salinity, and tidal inundation.

Several studies on nutrient dynamics have been carried out across various Indian mangroves, and a considerable hike in nitrate and phosphate has been observed. A study by Prasad et al. (2006) shows a decadal increase in the value of nitrate and phosphate in mangrove water from 1987–1989 till 1998–1999. They reported that a significant decadal increase in nutrients owes to the rapid degradation and conversion of mangroves to aquaculture ponds. Further studies in the same region show the mean value of nitrate to be 5.9 mg/l in 1995 which increases to 10.64 mg/l in 2003–2004 (Prasad et al. 2006). These values further increase to 34.6 mg/l in 2005 (Ranjan et al. 2008), and 29.9 mg/l of nitrate has been observed by Kumar et al. (2015). These hikes in nitrate might be due to land use and land cover changes including an increase in fallow land and aquacultural activities which discharged their effluents to this mangrove water. In Pichavaram, a tremendous increase in the values of nitrate can be observed after the tsunami (December 2004) which reaches the level of 34.6 mg/l in 2005 and 29.9 mg/l in 2006 (Fig. 8.3). Pichavaram shows an increase in nitrate from 5.9 mg/l in 1995 to 29.9 mg/l in 2006–2007. The sudden increase in nitrate values after the tsunami may be due to the retreating water, which carries the waste from agricultural and aquacultural fields to this mangrove ecosystem (Krithika et al. 2008). In Sundarbans it increases from 1.14 mg/l in 2001 to 3.69 mg/l in 2006 and in Godavari from 0.61 mg/l in 2001 to 2.25 mg/l in 2016.

In Fig. 8.3a, the value of phosphate shows a considerable hike in creek water in the past 25 years (Kulkarni et al. 2010). The value of phosphate shows consistent increase from 0.06 mg/l in 1982, 0.32 mg/l in 1989, 1.01 mg/l in 2000, and 2.19 mg/l in 2007. High phosphate concentration in Manori creek indicates a high pollution level as this creek is located in the close vicinity of Mumbai City, which is under high stress due to increasing anthropogenic activities and receives effluents from municipal and industrial wastes. Other human activities also contribute which include barrels and oil drums washing, boats manufacturing and unauthorized discharge of hazardous waste into the mangrove creeks (Zingde and Desai 1980).

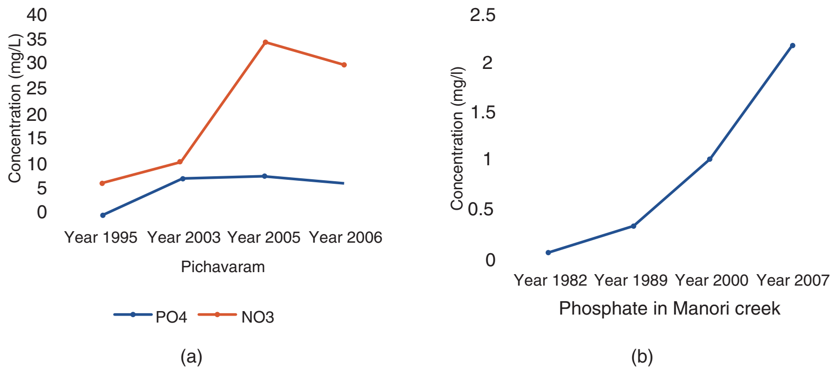

Fig. 8.3 Change in the concentration of phosphate: (**a**) Pichavaram mangroves, (**b**) Manori creek

Similarly, nitrate concentration in Godavari mangroves is 0.61 mg/l in 2001 (Tripathy et al. 2001) and increases to 2.25 mg/l in 2016 (Rao et al. 2018) which reveals human pressure mainly from effluents coming from aquacultural and agricultural runoff. Bhitarkanika has a value of 1.26 mg/l sourced by Dhamra port activities and agricultural runoff from the nearby villages (Chauhan and Ramanathan 2008), while Bhitarkanika aquacultural ponds have a value of 3.48 mg/l due to the use of diammonium phosphate (DAP) fertilizer.

(a) Nutrient ratio

Analysis of five major mangrove regions according to Table 8.2 was conducted to designate the ecological and nutrient status to study the influence of human perturbations. A standard Redfield ratio Si:N:P = 16:16:1 that defines the stoichiometric proportions of dissolved nutrients in the mangroves was found to be deviated due to the anthropogenic pressure. High input of silica to the mangrove waters due to terrestrial weathering is observed due to >1 Si:N ratios. Since the 1980s, there has been a significant increase in the dissolved nutrients mainly through sources like agriculture, aquaculture, etc. which is also depicted through decadal changes in the concentration of phosphate and nitrate in another study conducted in mangroves of Pichavaram. The presence of high DIP levels contributes to the deterioration of the water quality of Pichavaram through algal blooms, organic matter sedimentation, and depletion of oxygen. Further, the same fate has been followed by the rest of the areas. The nutrient levels in Coringa mangroves are influenced by the fluvial loads carried down from the river where allochthonous inputs are driven by agriculture and aquaculture practices, thus increasing BOD and algal blooms.

(b) Eutrophication

The elevated concentration of nutrients in coastal waters due to increasing anthropogenic activities leads to eutrophication. The increase in the nutrient loading causes increase in the harmful algal blooms which depletes the dissolved oxygen and induces toxicity leading to negligent quantities of marine fauna and disappearance. This leads to another change in the livelihood of villagers, extreme depletion in a fish catch caught over the past three decades due to effluent discharge and dumping of hazardous wastes. By enhancing the eutrophication, a shift in the phytoplankton is observed, that gives rise to blooms and further increased oxygen demands. India has the second largest population

Table 8.2 Dissolved nutrients (μM) and atomic ratios in the Indian mangrove ecosystems (Prasad 2012)

Mangrove	N:P ratio	Si:N ratio	Si:P ratio
Sundarban	11.43	53.01	4.64
Bhitarkanika	6.48	147.47	22.75
Coringa	5.46	25.87	4.74
Pichavaram	7.31	1.53	0.21
Mangalavanam	4.64	2.76	0.6

and is the fastest-growing country, so the coastal ecosystem of India could be extremely vulnerable to anthropogenically induced eutrophication.

Aquaculture

The tropical regions, especially Asia, have seen major losses due to aquaculture. Around 1 million ha of a coastal ecosystem has been converted to shrimp aquaculture. The shrimp sector development converts the flat, coastal lands to aquaculture ponds where a survey found about 5% of the shrimp aquaculture farms in India were constructed from past mangrove areas (ADB/NACA 1998). A study supported this by finding that in the Godavari delta in Andhra Pradesh around 14% of the aquaculture farms have been constructed on mangrove lands where the investigation was carried out by Andhra Pradesh Remote Sensing Application Centre. Around 80% of the mangrove land conversion occurs for shrimp aquaculture. It was observed that the rate of conversion increased from 1997 to 1999 implying that policy regulations could not prevent exploitation. From 1988 to 2013, the area under aquaculture has expanded which led to 5.04% of mangrove land being used up. According to the researchers, 35% of the worldwide mangrove loss (one-third) was due to the aquaculture that is assumed to reach 60% by 2030 (Lee et al. 2006). The modifications bring about massive landscape changes: a more urban infrastructure gets constructed that leads to change in geomorphology in the wetlands as well as the catchment area. Construction of dams and increase in water extraction demands to meet the growing population affect the coastal waters. Urban development converts the natural habitats to landscapes with impermeable surfaces which block the percolation of rainwater, thus changing the hydrology which degrades the downstream ecosystems and impacts the drainage networks which leads to more stormwater discharge in the receiving habitats (Singh et al. 2014). When we compare to other countries on the subcontinent, Bangladesh consists of the "Chakaria Sundarbans" with an area of 6020 ha, one of the oldest mangrove forests. It was the victim of shrimp aquaculture and salt production during the period of 1972 to 1989. Other countries like Thailand faced the same fate from 1918 to 1987 to accommodate the same practices. This study was directed to assess the trend of mangrove cover changes in five major mangrove-dominated countries of the subcontinent. Findings have suggested that the rate of loss of mangroves has fallen in India and Indonesia, whereas in Malaysia and Myanmar, the rate of loss amplified. The common cause of this loss was aquaculture for mangrove land conversion.

The adverse effect of aquaculture can be seen in groundwater which is an important and major source for drinking and other household purposes. Aquaculture affects the quality of water by changing its physicochemical aspects and biological activities. The physical aspect includes the pressure load on water. Chemical aspects include the extent to which it is polluting the water, and biological aspect includes the introduction of pathogens, microorganisms, exotic species, and several kinds of water-borne disease bacteria. It also causes the phenomenon of saltwater intrusion which is caused by the overuse of groundwater and its conversion to aquaculture ponds.

Oil Spills

Mangrove ecosystems are highly vulnerable to various anthropogenic activities; sometimes these activities lead to the accident like oil spills. They can happen during the extraction and transportation of oil across the world through the sea and the ocean. One of the greatest disadvantages of oil spills is that they remain in the environment for decades as they are not biodegradable and persist for a longer period. They affect the mangrove as they get deposited on the surface of the plants, roots, and soils and affect the marine life which depends on these plants and sediments (Duke and Burns 2003; NOAA 2014). Once deposited, oils get adsorbed to the oleophilic surface of both plants and animals except in the incidents where a large amount of oil have been spilled. In such cases, the oil does refloat and spread in a significant way with tidal flushing. Oil spillage causes the death of shorter plants and animals in few days, but the larger and mature may survive up to 6 months or more as oil coats the breathing surface of plant root, seedling, stems, and sediments. They also affect the fauna present in the burros and root hollows. Oil spills cause excessive harm to the aquatic fauna and seabirds. Globally, till now, around 238 notable incidents of the oil spill have been reported along the mangrove shorelines releasing a total of about 5.5 million tonnes of oil (Duke 2016). The oil spill, globally, has oiled around 1.94 million ha of mangrove ecosystems since 1958. This causes the death and decay of about 126,000 ha of mangrove vegetation.

A case study conducted in the Sundarban mangroves, Bangladesh, found direct influences on the ecosystem after the oil spill that occurred in December 2014 as shown in Fig. 8.4. The high content of oil (995 ± 429 mg/l) and high values of TSS (999 ± 447 mg/l), total hardness values (2156 ± 132 mg/l), and COD (377 ± 104 mg/l) were found in the region after the contamination. There are low transparency (12 ± 2 cm) and productivity (12 ± 2 cm) values with poor phytoplankton (32 ± 19 units/l) and zooplankton (7 ± 1.5 units/l) growth in the oil-contaminated

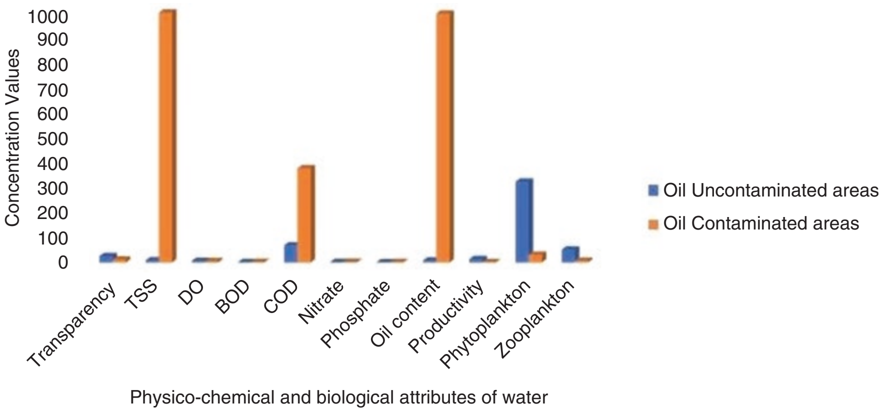

Fig. 8.4 Physicochemical and biological attributes of water of contaminated and un-contaminated areas. (Source: Harun et al. 2015)

areas. The biodiversity of mangroves gets affected by oil pollution with the Sundri plant getting covered with oil. On the other hand, the area having no contamination has better conditions. That comprises the western region which showed lower values of TSS (9.5 ± 1.8 mg/l), total hardness (965 ± 41 mg/l), and lower COD (69 ± 8). The oil content of more than 10 mg/l in aquatic habitat can also become lethal for aquatic lives (Lavate 2013). The soil of the intertidal zone in the oil-contaminated region showed higher oil content (1080 ± 420 mg/kg of 2 2-in. surface soil) than of the uncontaminated zones (5.5 ± 0.6 mg/kg of 2 2-in. surface soil). These findings through the study have shown how much oil spills can affect the coastal mangrove ecosystem (Harun et al. 2015).

Sand Mining

Another blow to the coastal habitat comes from the practice of "sand mining" that includes sand extraction from various environments such as beaches and inland dunes and dredging from ocean beds and riverbeds of deltaic regions (Pitchaiah 2017). Dried mangroves and red-colored ponds along the coastline of Kollam district of Kerala explain the widespread mining of beach sand mineral happening since the 1960s. Formation of sand bars and other interferences that include sand mining, oyster and mussel collection, and excess fishing in the Kozhikode and Malappuram districts of Kerala have witnessed the massive loss of mangrove vegetation (Bindu and Jayapal 2016). Along the Central Western Coast of India, a survey was undertaken along the two major estuaries Kundalika and Vasishthi in Maharashtra. The deterioration of these habitats gives rise to the demarcation of anthropogenic failures. Sand mining also contributes to the collapse of estuarine ecosystems. An increase in the suspended particulate levels and turbidity is followed by the input of oil and grease through vehicles used in sand removal accompanied by the changes in fish breeding. The fringing mangroves have been reclaimed to create human-enforced platforms which include landing stage for dredge vessels, loading trucks, stacking of sandbags and huts for laborer involved in trade with jetty kind of structures for cranes and winches, etc. With these perturbations to the extreme, the resulting habitat loss and modification are evident through the conflict between the livelihood crisis of the local fisherman community in comparison to bigger boats.

Resource Exploitation

Ethically very popular, the three Fs, fish, fuel, and fodder, summarize the importance of mangroves as a crucial form especially in terms of energy source for the local communities residing in the tropics. The chief origin of energy for domestic purposes in cooking and heating in the rural areas is derived from the forests in the form of firewood and charcoal. A study conducted in the Konkan region, Kolamb, Tarkarli, Sarjekot-Kalanwali, and Achara (Sindhudurg district) carried out the evaluation of calorific values and charcoal formation in the mangrove plant species which differs from species to species. It was found that Maharashtra charcoal is produced from mangroves illegally. Although Malaya is a major exporter of charcoal from the mangroves, in India this is limited. The sequential order obtained from the local information of best charcoal for burning within different species follows *Rhizophora* > *Avicennia* > *Sonneratia*, whereas laboratory experiments found a higher percentage of the coal from *Sonneratia* (54.48% charcoal) followed by *Rhizophora* (*R. apiculata*: 53.04% charcoal). The best fuel is represented by the calorific value, and in the present study, wood logs of *Avicennia officinalis* (5922.12 cal/g), *Rhizophora mucronata* (6739.95 cal/g), and *Sonneratia alba* (4062.28 cal/g) are continuously destructed for fuel purpose (Lavate 2013). Hence, the exploitation continues because of the high calorific value of the wood and high strength. Other activities including the chipboard and paper industry also influence the clearing of forests (Rasquinha and Mishra 2020).

The consequence of extracting the fuelwood on the mangrove ecosystem has received very little consideration. A study along the east coast, Bhitarkanika mangroves, investigated this impact upon the structure, arrangement, rejuvenation, and biomass and carbon stocks. This region comes second in species richness, sheltering the maximum diversity of true mangroves species in the country. Maximum harvested communities were mainly composed of mixed-species types dominated by the presence of *A. officinalis* and *Sonneratia* species, whereas non-harvested areas exhibited (58% of the sampled species) the presence of *Heritiera fomes* and *Excoecaria agallocha*, locally called as *sundari* and *guan*. Both of them are considered to be a rich source of timber and fuelwood locally.

Historical practices of chopping these trees for building and construction have been swapped by traded materials. The impact of frequent cutting can be reflected through the bushy and scrubby mangrove patches with abundant coppicing owing to frequent cutting revealing reduction (75%) in the species of *Heritiera* and *Avicennia* since 1970. However, another species *Phoenix paludosa* is used as thatching material for house and basket making, which has increased in extent due to plantation and restricted firewood cutting along with it serving as a nesting ground for estuarine crocodile, *C. porosus*. Further, the parameters designated for the investigation were lower in areas harvested for fuelwood with a species-specific difference across both forest types where it is observed that continuous harvesting can also drive the rare species to local extinction where much needed long-term research is required. Another factor that was brought to notice is shrimp cultivation where clearing of these forest patches to include aquaculture ponds is another pressing concern for this area (Jayanthi et al. 2018).

Acknowledging the socio-cultural needs of the local people and guiding the community management initiative hold significant potential for these regions to reduce exploitation and promote sustainable methods.

Other Pollutants

The rest of the contaminants in the water, sediments, and biota of the mangrove ecosystem include:

- Pharmaceuticals and personal care products (PPCPs)
- Polycyclic aromatic hydrocarbons (PAHs)
- Endocrine disrupter compounds (EDCs)
- Persistent organic pollutants (POPs)

In a study carried out on the Thane Creek of Mumbai, west coast, India, the sediments showed 15 PAHs ranging from 902.58 to 1643.60 and 930.69 to 1158.30 ng/g in Trombay and Vashi, respectively. The four major concentrations of carcinogenic PAHs obtained from pyrogenic and petrogenic sources were benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3-cd)pyrene, and dibenz(a,h)anthracene. These concentrations are higher in the Trombay region due to the leakage of petroleum products and boat engine oil due to the fishing activities and sailing of crude oil than in the Vashi area.

2 Importance of Mangroves in Controlling Pollution

From being considered as wastelands in the past to their present role as a natural sink of pollutants and carbon capture along with the buildup of heavy metals and biomagnification, these sheltered estuarine species have become a natural fighter against pollution, hence preventing seawater pollution. They are constantly creating a balance with the nutrient cycling in the coastal and estuarine ecosystems. They decrease the water flows and enhance sediment deposits, thereby arresting coastal erosion. Their surroundings become a land accretion zone as the sediments trap heavy metal contaminants. The inundation of mangroves results in lesser oxygen in the organic-rich sediments where the sulfate ions create sulfidic conditions that will also arise that leads to immobilization of metals in the mangroves where physicochemical changes are also seen in the rhizosphere (Sukhdhane et al. 2015). The specificity of mangrove remains constant in terms of carbon and nutrient cycles and sediment characteristics which can affect the bioavailability of contaminants by not only acting as a sink or transferring but also oxidizing the metals present in the sediments. They have chemical contaminants within pore water, overlying water, and sediment, SPM, and biota. The path of human history leaves a trail of major concentrations of nutrient and organic matter behind that can be seen through a budget created upon extensive study of the coastal wetlands.

3 Current and Future Threats

The continuous degradation over the coming years due to human development will bring about a change in the global climate patterns that includes the atmosphere and oceanic processes too. The rise in sea level, global warming, and change in weather pattern manifested by hurricanes and rainfall is expected to be faced by the mangrove ecosystems that will further test the persistence of these sentinel species. The major contradiction occurs when it is found that no sound study has been carried out till now about it on the Indian mangroves.

3.1 Global Warming

Elevation in the levels of greenhouse gases has led to a significant rise in the mean temperature, especially carbon dioxide that will align both physical and chemical changes in marine regions. Ever since industrialization, the concentration of CO_2 has increased from 280 ppmv in 1880 to 409.8 ppmv in 2019. In India, around nine tonnes of CO_2 is removed by the mangrove forests that is approximately equivalent to 270 million US dollars in the international market. Although the mangroves are not expected to suffer from sea surface temperatures, the effects can be related to the location and species-specific occurrences depending upon the local conditions. Although the increase in temperature shows higher productivity around the temperature of 25 °C that is ideal for photosynthesis if increased, the result will affect net productivity along with potential risk to the other communities being harbored by the mangroves along with a much-emphasized change in flowering and fruiting periods that will depend upon species to species. The rise in temperatures can lead to sediment oxygen demand which can worsen hypoxia and anoxia in the aquatic region. It was stated that the water temperatures increased at the rate of 0.05 °C/year while the DO reduced at the rate of 0.4 mg/l/decade over 27 years which is mainly attributed to the climate change (Sandilyan 2014).

3.2 Sea-Level Rise

The global rise of sea-level is one of major consequence of global warming that is already taking place and also recorded during the 20th century (12–22 cm). The most evident outcome of the sea level rise is characterized by an upward shift in species distribution as well as ecosystem mortality that increases towards the sea along with the export and accumulation of C, N, and P nutrients. The increase in temperatures causes thermal expansion of ocean water, and melting of polar and land ice will occur. The climate change-induced sea-level rise is increasing at a rate of 9–12 cm^{-1} where the current projections have been reported to be about 0.4–0.9.

In India, a recent study was conducted in River Hooghly which was a first report on the migration of the mangroves upstream in the river that was absent before 1995 (Ghosh et al. 2020). The species of *Sonneratia*, *Derris*, *Hibiscus*, and *Thespesia* were observed which were affected by the increase in pollution, increase in the COD, sea-level rise, etc. The river has been facing a rise in the mean sea level (MSL) and toxicity from the pollution load which ultimately gets discharged into Bay of Bengal, hence influencing the regional biogeochemical aspects of the sediments and response of mangroves which act as bioindicators. The growth of *Sonneratia* species along the upstream zones of the river is much faster compared to any other mangrove species. These kinds of variation in the micro-level environment accompanied by the human-induced threats will increase the frequency of coastal hazards, hence redirecting the threats to the human population (Sandilyan 2014).

3.3 Weather Events

These woody halophytes take their major reputation for being the natural saviors after the devastating tsunami of 2004. The presence of a complex root system in the mangroves dissipates the sea wave energy which ultimately prevents the coastal areas from the negative impact of the weather events taking place. The force and rate of recurrence of the tropical cyclones have a big role in damaging the mangroves through uprooting, defoliation, and tree mortality that will further lead to the ecosystem conversion. Moreover, the cleared mangrove area has not been able to be revived due to the change in the hydrodynamics, low nutrients, salinity, and acidity as well as deficiency in substrates.

4 Management: Restoration and Resilience

To preserve the mangrove forest, their management plays a vital role where strategies are needed to be adopted to regulate the pressures from human development. Although they provide higher ecological services, still their destruction through the 1960s, along with the Southeast Asian countries, tells a different story where more than half of the mangrove's forests were removed for the developmental activities (Ranjan et al. 2018). The notification of 1991 regarding the Coastal Regulation Zone (CRZ) has been leading the protection of coastal environments. A study conducted in Mumbai Metropolitan Region (MMR) that has witnessed a tremendous increase in industrialization and urbanization evaluated change in the ecology and biodiversity with actions taken by the government body in following rules and regulations for the betterment of the marine environment. These actions are responsible for investigating the sustenance of long-term environmental and socioeconomic aids. Due to a project in the Gorai village, around 700 acres of mangroves field was destroyed by spraying chemicals. Further, the Mulund-Thane belt saw a dispute arise around 2005 where the special economic zone (SEZ) was reserved on 134 acres of mangroves.

Although imbibed right from the seventeenth century, their official report on "Status Report of Mangroves of India" was sent in 1987. Previously, the importance was not recognized that led to exploitation on the rise and hence huge losses in almost every country where it was also reported that the loss was even faster than coral reefs and tropical forests.

In India, the management of coastal woodlands is carried out using three major strategies: promotory, regulatory, and participatory.

- Promotory approach: Implementation by the Government of India, Management Action Plan (MAP) within 38 mangrove regions.
- Regulatory approach: The protection of mangroves is supported by policy methods and legal support through parks, sanctuary, reserved forests, and effective legislations which are often challenged by lack of financial support, poor infrastructure, and other socio-political demands. An example that can be carried forward is the condition of mangroves in Myanmar where the human pressure as well as political instability led to additional environmental degradation along with a poor economy that threatened the recovery.
- Participatory management: Stakeholders from the industrial sectors are an essential factor for this kind of approach.

4.1 Management Activities on Regional Scale

This can be explained by the following examples.

In India, along the east coast within the states of Tamil Nadu and Andhra Pradesh, a technique referred to as "Fish Bone" design was adopted for restoration of mangroves demonstrated by the M.S. Swaminathan Research Foundation in Chennai and Forest department as "Canal Bank Plantation" that increased the tidal inundation and made the soil suitable for growth by decreasing the amount of salt concentration. This technique was helpful in the restoration of forest cover by about 90% in the Pichavaram mangroves (1986–2002) along with the support of local communities. Another conservation model leads us to Maharashtra "Mangrove Cell" that was set up in January 2012, which till today has led to Maharashtra becoming the first Indian state to declare the state mangrove tree, *Sonneratia alba*, as the symbol of conservation (News report, Hindustan Times, 2020). Following the protocols, more plantations in the degraded areas and other marine-based projects have been undertaken to follow the conservation of biodiversity that successfully projects a holistic approach towards coastal ecosystem as well as marine region conservation in association with many several institutes, agencies, as well as NGOs. In May 2014, the Kannur region of Kerala undertook safety of its mangrove population by conducting a survey and declaring 236 ha mangroves as "Reserved Forest" and further acquiring them from private owners (News report, The Hindu, 2015).

Community-based co-management of mangroves in India occurs mainly in the states of West Bengal, Andhra Pradesh, Odisha, Tamil Nadu, and Gujarat, for example, restoration of 1475 ha mangroves by plantation of 6.8 million mangrove saplings by the JMM project that involved 5240 families from 28 villages on the east coast of India. Similarly, along the Gujarat coast, a project from 2001 to 2006 was managed around 5000 ha of mangroves and regeneration (Kathiresan 2018). The application of remote sensing becomes an efficient method of mapping and monitoring the mangroves. Their occurrence in inaccessible areas can be easily differentiated through the presence of conspicuous signatures in the satellite images. According to the India State of Forest Report, the analysis of satellite data along with the Geographical Information System (GIS) is the most effective way to monitor the mangrove ecosystems. The states which have witnessed a major degradation in the mangrove area are executing various measures for the conservation and management of these species.

5 Conclusion

The mangroves have been surviving the anthropogenic changes since the onset of urbanization and industrialization along the coast and adapting to the negative implications. This review of case studies across the coastal regions of India highlights various pathways through which the degradation of mangroves is being accelerated. The result of continuous mangrove degradation has been discussed with a major focus on the input of nutrients, heavy metals, oil spills, etc. contaminating the water and sediment. A consistent increase in the trace metals has been observed in the Sundarbans, Pichavaram, and Goa mangroves. The nutrient content shows a considerable increase hike in almost all the studied mangroves. Pichavaram shows an increase in nitrate from 5.9 mg/l in 1995 to 29.9 mg/l in 2006–2007. In Sundarbans it increased from 1.14 mg/l in 2001 to 3.69 mg/l in 2006 and in Godavari from 0.61 mg/l in 2001 to 2.25 mg/l in 2016. The phosphate values increase from 0.28 mg/l in 1995 to 6.6 mg/l in 2006 in Pichavaram mangroves. Manori creek, Mumbai, shows an increased hike in phosphate in the past 25 years. The value increases from 0.06 mg/l in 1982 to 2.19 mg/l in 2007. Further, in the case of oil spills, the oil content can become lethal for the aquatic species causing a reduction in biodiversity, destabilizing coastal habitat. In pristine conditions, the ecosystem can absorb disturbance and regenerate while facing alterations, also retaining similar controls on the structure and functioning. Due to the continuous damage being implicated on the ecosystems, these species can succumb to the negative pressure and become more vulnerable to the changes from being in reversible to irreversible states. Thus, we need to conserve, protect, and restore the mangrove ecosystem for the value they have and prevent degradation from reaching a threshold that can collapse their resilience (Begam et al. 2020). Restoration of mangroves can become a unique approach to decrease the emission of carbon dioxide to the atmosphere, thus mitigating climate change due to global warming.

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