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Effects of Anthropogenic Pollution on Mangrove Biodiversity: A Review

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ABSTRACT

Mangrove ecosystem is a very unique ecosystem in the Earth, which is under threat due to habitat loss, aquaculture expansion, overharvesting and increase of pollution load. In this review paper, world-wide status of mangrove habitat loss, the role of mangrove to act as a sink of pollutants and carbon capture (carbon sequestration), accumulation and biomagnifications of heavy metals is discussed. Emphasis has been given to understand the effect of heavy metals, organic and inorganic pollutants on the mangroves and the natural ability of this ecosystem to tolerate the pollution load. Lastly the guidelines of mangrove research for the developing countries are also suggested.

Keywords: Mangrove Biodiversity; Trace Metals; Carbon-Sequestration; Pollution Sink; Mangrove Deforestation

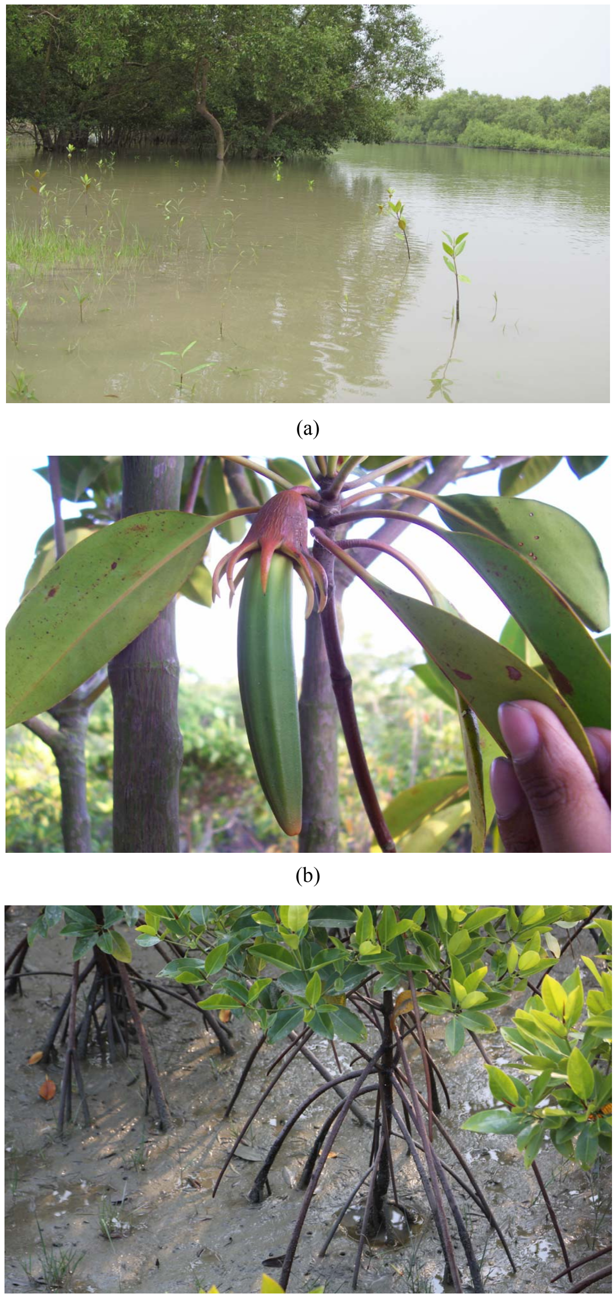
1. Introduction

Mangroves are coastal forests found in sheltered estuaries and along river banks and lagoons in the tropics and subtropics. The term "mangrove" describes both the ecosystem and the plant families that have developed specialized adaptations to live in this tidal environment [1]. Its multifaceted role, including the interactive relationship with the neighboring habitat and sheltering diverse species, has made it a treasured storehouse of the nature particularly production of fish and shellfish. Mangroves are one of the most productive ecosystems that enrich coastal waters, yield commercial forest products, protect coastlines, and even support coastal fisheries and storehouse of numerous endangered faunas (like *Panthera tigris tigris*, dolphin, otters, manatees and numerous avian species like egrets, pelicans, eagles) [2,3]. Estuaries are regions of enhanced biogeochemical activity and impart important ecosystem services along with supporting complex food webs [4]. Mangroves act as a fragile link between marine and fresh water ecosystems, pollution sink and source of nutrient flux into marine ecosystem. But, one is bound to be surprised to know that such a natural fighter against pollution is constantly being affected by the rising level of pollution. The aim of the review paper is to find out how this unique ecosystem, even if being adversely affected by pollution, still sustains the seminal balance of the ecosystem and plays a key role in nutrient cycling in coastal and estuarine ecosystem.

Mangrove restoration work has been carried out in the Tutuila Island, American Samoa [5]. They are in opinion that rehabilitation sites must meet the environmental conditions (e.g., duration, frequency and depth of inundation, wave energy, substrate conditions, salinity regime, soil and water pH, sediment composition and stability, nutrient concentrations, elevation, slope) required by mangrove species indigenous to the area.

2. Mangroves—A Unique Ecosystem with Rich Species Diversity

Basically Mangroves are woody halophytic plants, which exist in the conditions of high salinity, extreme tides (**Figure 1(a)**), strong winds, high temperatures and muddy-anaerobic soils. The halophytic adaptations of mangroves, such as vivipery (**Figure 1(b)**), support roots (**Figure 1(c)**), negatively geotropic breathing roots (*i.e.*, pneumatophores), sclerophyllous leaves with salt excretion glands and sunken stomata, stilt root and root but



(a)

(b)

(c)

Figure 1. (a) Mangroves at Indian Sundarbans (Satjelia Island) inundated by tidal waters; (b) *Bruguiera* sp, showing viviparous germination; (c) Stilt root (support root) of *Rhizophora mucronata* lamk.

tress are all indicative of the evolutionary selection to persist in muddy, brackish coastal environment on physiologically dry soil.

Mangroves are salt tolerant species and can take up water despite of high osmotic potential of soil water and even if the salt is absorbed, it is excreted through the salt glands in the leaves.

To mark out the general mangrove community along with other flora and fauna, the term "*mangal*" was proposed [6].

The exact number of species is still under discussion and ranges from 50 to 70 according to different classifications [1] with the highest species diversity found in Asia, followed by eastern Africa. In India, if all vascular plants are taken into consideration, east coast has 64 species (42 genera and 29 families) whereas the western coast has 33 species (24 genera and 19 families) and Andaman and Nicober Island has 43 species (30 genera and 23 families). About 60% of Indian mangroves are present in the east coast along Bay of Bengal, 20% in west coast along Arabian Sea and 13% on Andaman and Nicobar islands [7]. Mangrove forest cover in India is classified as very dense (>70% plant cover, 1405 sq km), moderately dense (40% - 70%, 1659 sq km), and open type (10% - 40%, 1575 sq km) forest types [7]. It is reported that Sunderbans alone has 62 species of mangroves [8]. The Indo-Malaysian region is considered to be the centre for the evolution of Mangrove vegetation [9].

Mangrove ecosystems can be used as indicators of coastal change or sea-level rise. These ecosystems are so specialized that any minor variation in their hydrological or tidal regimes causes noticeable mortality [10]. Mangrove ecosystem also serves as conservation of nutrients by storing them in dead roots ranging from 36% - 88% of total living tree biomass [11], unlike terrestrial forests where a large proportion of nutrient capital is stored in floor litter.

3. Loss of Mangrove Ecosystem

Unfortunately this unique ecosystem is itself being destructively harmed by the progress of civilization. Recent assessments on extent of mangroves worldwide suggests that between 1990 and 2010 there is a reduction of 3% of mangroves cover throughout the world and reasons are primarily land conversions for coastal development, rice production and aqua cultural projects [12]. However during 1980-2005, the aerial extent of mangrove forest loss is 30% - 50%, as a result of coastal development, aquaculture expansion, and over harvesting, which accounts for 36,000 km^2 [3]. Current extents of mangrove areas in different countries are represented in **Figure 2**.

About 25 countries of Asia have mangrove ecosystem, with climatic variation, ranging from arid (Arabian Peninsula) to sub-tropical (China, Japan) to humid tropical (South East Asia) [3]. Asia has the largest mangrove area in the world, with highest biodiversity of more than 50 species of true mangroves. Amongst them some are regional endemics like-*Aegiceras floridum*, *Camptostemon philippinensis*, *Heritiera globosa*. *Kandelia candel* a Rhizophoraceae member is found in north as far as Japan but is rare in SE Asia. High rainfall and substantial fresh

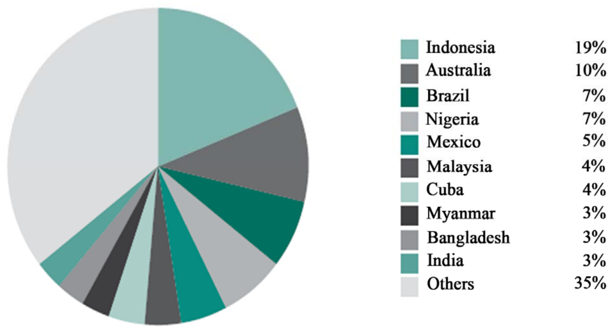


Figure 2. Percentage of mangrove area by country [3].

water input from rivers makes Bangladesh, India, Malaysia, Thailand and Indonesia a favorable place for growth of well structured mangroves, where the trees grow to a height of 30 - 50 m.

In Asia, Sundarbans, is the world's largest contiguous mangrove patch covering an area of 10,000 km^2 and is the part of the progradation delta of Ganga-Brahmaputra-Meghna river systems that comprises of an area of 80,000 km^2 [13-15] and recognized internationally as the UNESCO (United Nations Educational, Scientific and Cultural Organization) World-Heritage site, The transboundary forest of Sundarbans is spread over two countries, of which 60% is in Bangladesh and 40% in India. This mangrove ecosystem is affected by numerous cyclonic storms [16]. But that is also to some extent threatened by the above mentioned problems. Asian mangroves as a whole is affected by anthropogenic disturbances like intensive logging, land conversion to promote paddy cultivation and aquaculture and pollution [3]. According to the estimate, since 1980, 25% loss of mangrove has been observed in Asia which was mainly due to intense deforestation activities [3]. So in current scenario the need of the hour is to conserve this fragile ecosystem. Though mangrove ecosystem is an important focus for conservation biologists, environmentalists but the growth of public consciousness to conserve mangrove ecosystem still remains as the burning question [17,18].

4. Mangrove Soil and Water-Act as a Pollution Sink

Like all other green species, Mangrove has got definite role against the pollution. It has natural ability to act as a sink of anthropogenic and industrial pollutants. Mangrove ecosystems are specific in numerous aspects (e.g. carbon and nutrients cycles, sediment characteristics, tidal conditions) which are expected to affect the speciation, and therefore the bioavailability of contaminants [19]. It can also arrest and bioremidiate certain pollutants (like fluoride) in local environment [20,21]. It not only acts as a sink or transfers the pollutants but also oxidizes the metals present in the sediment by exuding oxygen into the anoxic soil through aerial roots [22]. Mangrove wetlands are used for low cost waste disposal site [23,24]

Rise in industrialization and uncontrolled anthropogenic pressure on virgin mangrove patches has been increase in recent years, however, mangroves ecosystem adapted themselves by acting as natural pollution sink. Mangrove soils/sediments are usually fine-grained, water-logged and receive allochthonous organic matter from terrigenous origins [17]. Chemical contaminants in mangrove ecosystems are present between pore water, overlying water, and solid phases such as sediment, suspended particulate matter and biota [17]. According to the previous review work, the inundation of mangroves generally results in the depletion of oxygen in the organic rich sediments [19]. Since sulfate ions are usually present in large supply, sulfidic conditions will also arise. The stratification of redox conditions, from suboxic to anoxic and sulfidic, was reported for unvegetated sediments and those covered with mangrove plants. In the sulfidic zones, the co-precipitation of trace metals together with other sulfide minerals (e.g. iron sulfide) is described as a major process leading to the immobilization of metals in mangroves. Physico-chemical changes in the rhizosphere are also seen to be associated with changes in the concentration and the speciation of trace metals [19].

4.1. High Absorptive Capacity of Mangrove Sediment

Salt marshes or mangroves are characterized by highly anoxic reducing soil, with high decomposer activity [25]. It is argued that these estuarine and salt marshes ecosystems have sediment with high sorptive capacity, which could be used as a primary sewage treatment where the nutrient from the sewage load would also be instrumental in boosting the productivity of the ecosystem [26]. *Spartina* sp grown in salt marsh reported to bioaccumulate elevated amount of heavy metals and dead plants are observed to contain even more concentration of heavy metals namely Fe, Mn and Zn than the live plants [27]. Work at New England salt marshes reported that 20% - 30% of Cd, 20% - 50% of Cr, 60% - 100% of Cu, 80% - 100% of Pb and Fe of the total is retained by the salt marsh sediment [26]. Similar work at Red mangrove (*Rhizophora mangale*) marshes at Sepetiba Bay, Rio de Jenerio also reported that 95% of the total concentrations for Fe, Cu, Cd, Pb, and Cr, exist in strongly bound faction and is unavailable to the plants [28]. Mangal ecosystem and litter are poor in trace metal content leading to a very low export rates [29].

Mangrove ecosystem retains toxic metals and stops it from infiltrating into the marine ecosystems. Different mangrove forest areas across the world have varying level of pollution load. A correlation is observed between total organic carbon (TOC) and heavy metal concentration [30]. Different literature of investigation in different mangrove patches confirms the presence of pollutants in the ecosystem. Salinity in estuaries is also responsible for changes in adsorption processes for metals [31]. The increase of the salinity is associated with an increase in the concentrations of major cations (Na, K, Ca, Mg) that compete with heavy metals for the sorption sites.

Marine, estuarine organisms can bioaccumulate trace metals and pollutants and it is expressed by biota-sediment accumulation factor (BSAF) which is actually a ratio of concentration of pollutants in the tissue and concentration of the same pollutant in the sediment. Recent research [30], shows that in descending order of BSAF the metals in the sediment and mangrove flora of Hainan island in China are Hg (0.43) > Cu (0.27) > Cd (0.22) > Zn (0.17) > Pb (0.07) > Cr (0.06) >As (0.02), where Hg has the highest BSAF value owing to it's physical property of semi volatile element and essential metal like Cu have higher BSAF than non essential metals because of its high mobility in plant tissues.

4.2. Asphyxiated Condition

Environmental degradation due to impact of nutrient and heavy metal pollutants, can give raise to asphyxiated swamp, where Dissolved Oxygen (DO) falls. There is a substantial amount of litter, vegetation present in the mangrove ecosystem for decomposition by microbial action and through detritus food chain. But lack of oxygen is eventually gives rise to the dead zone [32]. The term "Dead zone" is used [32], to describe the decreased amount of DO in bottom waters that form in each summer at North of Gulf of Mexico. The investigation at asphyxiated swamps, [33] in the Qua Iboe estuary mangrove ecosystem revealed a relatively high concentration of organic carbon in epipelic sediment is due to the decomposition of litter and hydrolysis of tannins in mangrove plants. Again presence of the high levels of nutriative salts such as CO_3^{2-} (111 mg/kg), SO_4^{2-} (201.5 mg/kg), Cl^- (142.5 mg/kg) and NH_4^+ (178.8 mg/kg) in the epipelic sediments of asphyxiated pond indicates the impact of anthropogenic activities [33]. Tomlinson Pollution Load Index (PLI) to assess the level of contamination by using the formulae [1] as;

$$CF = \frac{C_{\text{Sample}}}{C_{\text{Background}}}$$

$$PLI = \sqrt[n]{CF1 \times CF2 \times \cdots CFn}$$

where,

CF = contamination factor;

n = number of metal;

C_{Sample} = metal concentration of sediment and;

$C_{\text{Background}}$ = mean metal concentration from healthy mangrove swamp.

PLI is indicative of number of times the contamination of metal in sediment exceeds that in natural unpolluted environment.

The mean concentration of metals (mg/kg. dw) namely Zn, Cu, Ni, Pb, Cr and V in sediment at asphyxiated and healthy mangrove ecosystems of Qua Iboe vary from 36.3 - 179.4, 29.2 - 43.2, 3.6 - 37.4, 39.6 - 93.8, 0.15 - 0.53 and 2.9 - 9.3, where the former have higher metal accumulation potential [33].

Several studies reported the accumulation of non-nutrients metal in mangrove sediment and bioaccumulation to aerial tissues. Mangrove ecosystem is used as an effective pollution sink, where the pollutants from different industrial and anthropogenic activities are diverted into the mangrove ecosystem. Paper and petroleum effluents are also one of the major sources of pollution in mangrove ecosystem. The, toxicity studies for mangrove plants have focused on the effects of trace metals (Cu, Cd, Hg, Mn, Pb and Zn), oil residues, some herbicides and raw wastewater. Under controlled conditions, the effect of trace pollutants on mangrove plants were studied in detail and it reveals that photosynthesis, growth, and biomass was reduced due to their effect and it finally increases mortality [34]. In Indian Sundarbans mostly untreated effluent from a number of small and large factories are dumped into Kulti river (**Figure 3**) which mixes with the waters of sunderbans, which is approximately 35 km south-east of the city of Kolkata, as shown in **Figure 3** [21].

4.3. Biotransformation and Bioaccumulation

The contaminant accumulation in sediments and bioaccumulation pathway on mangrove ecosystem is presented in **Figure 4**. Scientific reviews elucidated the fate and effects of trace metals (22 metals) released from anthropogenic sources in the mangrove ecosystem [17]. The metal concentrations in mangrove sediment, along with their bioavailability and bioaccumulation in tissues were studied by several workers [17,19].

Figure 3. View of sewage discharge from Kolkata at Sundarbans (near Ghusighata).

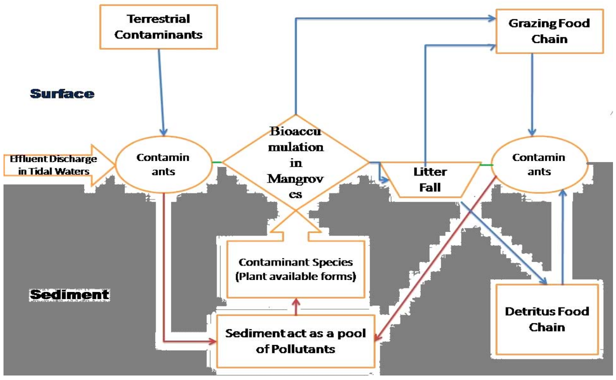


Figure 4. Contaminant pathway in the mangrove ecosystem.

The metal concentration in sediment often differs geographically for the same trace metal. Literatures indicated that, out of all trace metals Mn accumulation was reported highest (sometime Fe) and least for Cd. The general sequence is Mn (=Fe) > Zn > Cr > Pb > Cu > Cd. Concentration of metals (µg/gm dry wt) in mangrove tissues is reported as Mn (4.5 - 2472) > Zn (0.7 - 1988) > Pb (0.02 - 225) > Cu (0.5 - 207) > Cd (0.01 - 3.1). Different species have shown different degree of metal accumulation potential.

Metal concentration is usually higher in mangrove roots than aerial parts. BCF (Bioconcentration Factor) are usually low in mangrove tissues other than roots, thus mangrove tissues are not generally considered as effective indicator of pollution. Out of 60 mangrove species, 33 species are used for toxicity test [17]. Metals are present in mangrove tissues as a result of speciation of metals in sediment, exclusion at root level and physiological adaptation of mangrove plants to prevent bio-accumulation [19]. Scientific studies on effect of pollution on mangrove plant is studied using biological responses like survival, biomass production, defoliation, effect on photosynthesis, expression of metallothioneins and enzymes. It is reported that under controlled condition trace pollutants are responsible for reduction of photosynthesis. Among trace metal, a LC_{50} of 580 µg/ gm of Zn is reported from controlled study on *Avicinnea marina* seedling. *Avicinnea* is of cosmopolitan distribution and is thought to have higher metal accumulative property than other mangroves.

There Cu and Pb were found to be accumulated in higher concentration in root tissues than sediment concentrations, whereas in leaf tissue Cu, Zn was found more than 10% of that in the root [35]. Out of three metals, Pb is the least mobile element. It is found that *A. marina* can act as a bioindicator of metal pollutants namely Cu, Zn, and Pb as there is a linear relationship. Another investigation at Bhitarkanika coast of Orissa (India) revealed that *A. officinalis*, can accumulate the highest concentration of Fe, Cu, Mn, Zn amongst five mangrove species, namely *Xylocarpus granatum*, *Bruguiera cylindrica*, *Rhizophora mucronata* and *Ceriops decandra* [36].

There is a trend of change in mangrove biodiversity in different parts of the globe. Most of the investigation is revolving around the bioaccumulation potential of different mangroves, which reveals that *Avicinnea* sp is one of the most tolerant species in respect to heavy metals, amongst mangroves. In Indian scenario there is a clear increase of *A. marina* in different mangrove patches. Thus one can derive at this point that pollution factor can also be a potential reason for their dominance. So more pollutants would mean proliferation of only pollution tolerant mangroves to flourish and ecosensitive species would be replaced, and henceforth would result in deterioration of mangrove biodiversity.

4.4. Other Contaminants in Mangrove Ecosystem

Literature reviews stated that trace metals, Polycyclic Aromatic Hydrocarbons (PAHs), Persistent Organic Pollutants (POPs), Pharmaceuticals and Personal Care Products (PPCPs) and Endocrine Disrupters Compounds (EDCs) have been detected in various mangrove compartments (water, sediments and biota) [19]. These pollutants affect the mangrove ecosystem species, with potential impact on populations and biodiversity. Metals can enter mangrove ecosystem through rivers, marine water intrusion or through atmospheric deposition. Mangrove sediment is rich in organic carbon (OC). It is observed that Particulate Organic Carbon (POC), varies greatly between locations, like 0.61% - 1.57% is recorded from Sunderbans, 0.52% - 3.02% near Mumbai, India and 2.69% - 5.96% in Deep Bay, China. It is observed that OC of underlying soil of *Rhizophora* sp is present in higher proportion than the soil beneath *Avicennia* strands. It implies that true mangrove species have higher carbon sequestering potential than associates.

5. Mangrove Acts as an Effective Carbon Sink

Carbon emission is the major cause for climate change and global warming. There is a 36% raise in global CO_2 emission from 1992 to 2008 and it shows a steady mean increase from 357 ppmv (parts per million by volume) in 1992 to 389 ppmv in 2011 [12]. Mangroves act as an effective carbon sink [37] and sequester higher amount of CO_2 (than any other non-mangrove forest types) which approximately amounts to 100 tons of CO_2 per hector (Ha) and also stabilize the soil particles to control erosion [38]. Mangroves are most carbon-rich forests in the tropics and well known for high carbon assimilation and flux rates. Another estimate elucidates that coastal and estuarine mangrove forests retains 1023 Mg carbon per hectare

[39]. While, comparing the carbon storage capacity (both above and below ground) of mangroves ecosystem with other ecosystems, mangroves has superiority and could be act as effective carbon sink. Decomposing of mangrove litter is rapid in wet soil which adds to the carbon flux of the soil thereby increasing the total organic carbon of the soil. Organic rich soils ranged from 0.5 m to more than 3 m in depth and accounted for 49% - 98% of carbon storage [39]. Mangrove deforestation generates emission of 0.02 - 0.12 Pg carbon/year, as much as around 10% of emissions globally [39] despite accounting for about 0.7% of tropical forest area [40].

6. Conclusion

It will be a mere repetition if we again elaborate or point out the multilayered function of this unparallel ecosystem. Therefore protection and conservation of mangrove ecosystem in the developing countries should be given priority. Along with the above factors, chemical pollution, particularly accumulation and bio-transformation of toxic metals could be a significant factor for reduction of mangrove biodiversity. Mangrove sediment is soft and muddy, extended up to a depth of 3 - 4 m, rich in organic carbon, and acted as a "carbon reservoir". The assessment of distribution of carbon profile (both spatial and temporal) is essential to determine the C-sequestration potential of mangrove ecosystem for developing countries.

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