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Review

Metals in mangrove ecosystems and associated biota: A global perspective

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ABSTRACT

Mangrove forests prevalent along the intertidal regions of tropical and sub-tropical coastlines are inimitable and dynamic ecosystems. They protect and stabilize coastal areas from deleterious consequences of natural disasters such as hurricanes and tsunamis. Although there are reviews on ecological aspects, industrial uses of mangrove-associated microorganisms and occurrence of pollutants in a region-specific manner, there is no exclusive review detailing the incidence of metals in mangrove sediments and associated biota in these ecosystems on a global level. In this review, mangrove forests have been classified in a continent-wise manner. Most of the investigations detail the distribution of metals such as zinc, chromium, arsenic, copper, cobalt, manganese, nickel, lead and mercury although in some cases levels of vanadium, strontium, zirconium and uranium have also been studied. Seasonal, tidal, marine, riverine, and terrestrial components are seen to influence occurrence, speciation, bioavailability and fate of metals in these ecosystems. In most of the cases, associated plants and animals also accumulate metals to different extents and are of ecotoxicological relevance. Levels of metals vary in a region specific manner and there is disparity in the pollution status of different mangrove areas. Protecting these vulnerable ecosystems from metal pollutants is important from environmental safety point of view.

1. Introduction

Mangrove forests are found along intertidal regions of tropical and sub-tropical coasts. These ecosystems cover approximately 75% of world coastlines that lie between 30° N and 30° S (Giri et al., 2011). They are estimated to occupy an area of around 156,220 square km (Ghosh et al., 2015). They are distributed over 118 countries and territories in the tropical and subtropical regions of the world. Mangrove forests in general, play a significant role in protecting and stabilizing coastal zones and in warding off harmful effects of natural calamities such as hurricanes and tsunamis (Alongi, 2002, 2007). The biotic components associated with mangroves rapidly adapt to unfavorable environmental conditions and effectively cope up with periodic tidal flooding, fluctuating salinity, water logging, anoxic conditions and high temperatures (Hogarth, 2015). Survival and zonation of mangrove trees depends on morphological and physiological adaptations to soil (type and chemistry), nutrient contents, salinity, physiological tolerances and competition (Kathiresan and Bingham, 2001). Additionally, the biological richness (microorganisms, plants, invertebrates, to mention a few), composition of forest structure (biomass, wood density, litter structure) and various abiotic factors (soil pH, organic and moisture content) make mangrove ecosystems immensely unique and productive (Das, 2017). Biological forms found here have been sources of different biotechnologically relevant products (Khot et al., 2012, 2015; Kamat et al., 2013; Kakkad et al., 2015). Mangroves act as nursery habitats for juvenile fish. They provide fish with food and protect them from predators (Benzeev et al., 2017; Carrasquilla-Henao and Juanes, 2017). Due to habitat complexity, density of fish is generally found to be higher in mangroves. Mangrove forests thus provide a variety of ecosystem services and favor socio-economic welfare of humankind.

Mangroves on a global scale are distributed in all continents (Fig. 1). They are seen in Australia, Asia, Africa, South and Central America. Diversity of mangrove species is found to be the highest in Asia and Australia (Selvam et al., 2000; Ravishankar et al., 2004).

Mangrove ecosystems are exposed to a variety of contaminants and anthropogenic agents. Wastewater run-offs, industrial effluents, atmospheric and marine activities are major contributors in this regard. Heavy metals such as copper (Cu), zinc (Zn), manganese (Mn), cadmium (Cd), chromium (Cr), lead (Pb) and mercury (Hg) are particularly important in these ecosystems (Silva et al., 1990). Such metals are generally persistent and tend to accumulate in food chains. Their contents are higher in sediments where they form complexes with particulate organic carbon; iron oxyhydroxides and sulphides (Chapman et al., 1998; Ranjan et al., 2008). Changes in physico-chemical

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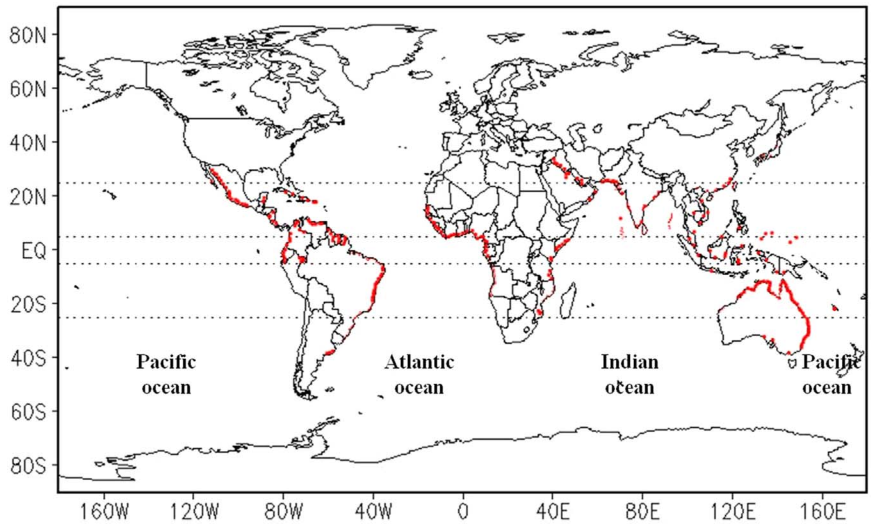

Fig. 1. Distribution of mangroves on a global scale.

parameters (pH and redox potential) and biological processes mediate the transfer of sediment-trapped metal species into the overlying water (Morgan et al., 2012; Li et al., 2014a, 2014b, 2014c).

Literature survey on the topic shows that there are reviews [i] discussing the ecological aspects of mangrove plants and related microbial communities with respect to productivity, spatial variation of contaminants and reforestation of contaminated areas (Peixoto et al., 2011; De-Bashan et al., 2012) [ii] describing the industrial applications of mangrove-associated microorganisms (Thatoia et al., 2013) [iii] highlighting the incidence of pollutants in mangroves systems (Lewis et al., 2011; Bayen, 2012) [iv] summarizing the occurrence of contaminants in these ecosystems in a limited and region-specific manner (Tam, 2006; Zhang et al., 2014). However, to the best of our knowledge, there is no exclusive review detailing the occurrence of metals in mangrove ecosystems at the global scale and understanding the impact of these metals on the associated biota. In this review, the literature available on these topics has been categorized in two sections (i) Occurrence of heavy metals in abiotic components (soils, sediments and overlying water samples) of mangrove ecosystems and (ii) uptake and distribution of metals in the associated biotic components (plants and animals). The impact of bioaccumulation on human beings has also been addressed.

2. Occurrence of heavy metals in abiotic components of mangrove ecosystems

Generally, heavy metals are persistent and tend to accumulate in different type of environments. Sources of metal contamination can be natural or anthropogenic. Increasing industrial and anthropogenic activities in the recent past have aggravated this problem to a greater extent. Above a threshold concentration, metals often become hazardous and pose a threat to the associated biota including human beings.

In mangrove ecosystems, soils, sediments and overlying water are the major abiotic components. Sediment quality is an important parameter that decides the overall productivity of an ecosystem. Sediments act as major sinks for pollutants including metal ions (Caccia et al., 2003). Phenomena such as adsorption, desorption, precipitation, diffusion, chemical reactions, and biological activity play a vital role in this regard (Chatterjee et al., 2009). In some cases, they may contribute towards pollution in a significant manner (Adams et al., 1992; Burton and Scott, 1992). Various regulating factors such as pH, salinity, grain size, redox potential and organic carbon content control the distribution of metals in mangrove soils and sediments. These factors also govern soil quality, sediment texture and distribution of metals in such ecosystems. Several standard geochemical indices including, geo-accumulation index [$I_{geo} < 0$: pollution free; $0 \le I_{geo} < 1$: pollution free to moderately polluted; $1 \le I_{geo} < 2$: moderately polluted; $2 \le I_{geo} < 3$: moderately to strongly polluted; $3 \le I_{geo} < 4$: strongly polluted; $4 \le I_{geo} < 5$: strongly to very strongly polluted; $I_{geo} \ge 5$: very strongly polluted (Deepulal et al., 2012)]; Enrichment factor [EF with values around 1 signifying lithogenous inputs and higher values indicating human inputs (Nolting et al., 1999)]; Contamination degree [$Cd < 7$: low level; $7 \le Cd < 14$: moderate level; $14 \le Cd < 28$: considerable level; and $Cd \ge 28$: very high level (Hakanson, 1980)] have been used to predict pollution levels. In addition, pollution load index (PLI), threshold effective level (TEL), effect range low (ERL), probable effect concentration (PEC), toxic effect threshold (TET), severe effect level (SEL), effect range median (ERM) and probable effect level (PEL) values decide levels of metal pollution (Veerasingam et al., 2012; Usman et al., 2013). On the basis of these parameters, concentrations of heavy metals, their level of pollution and their probable risk to the associated biota have been described by different investigators. Based on this information, potentially threatened regions and pristine areas can been identified. In the following sub-sections, levels of metal contaminants in mangrove areas pertinent in different continents have been detailed.

2.1. Australia

In the Australian continent, Homebush bay near Sydney appears to be polluted with metals over a long frame of time. Clark et al. (1997) about twenty years back have shown that metal contents in this area vary in a seasonal manner with geogenic and anthropogenic activities affecting their distribution patterns. Later studies have also indicated metal pollution in sediment samples from some areas in Sydney estuary (Birch, 2000; Birch et al., 2007). As seen in Table 1, high levels of Pb and moderate levels of nickel (Ni), Zn and Cu have indicated a deterioration of sediment quality over a period of time (Birch et al., 2015). According to the authors, increased metal ion contents were attributed towards industrial activities or mobilization of contaminated sediments in the bay. Arsenic (As) concentrations did not pose a threat and were comparable to earlier reported levels (Taylor et al., 2004; Birch et al., 2013). In the mangroves of New Caledonia, an island towards East of Australia, high contents of iron (Fe) and Ni have been reported (Marchand et al., 2011, 2016). Soils in mangrove sediments of Pumicestone region, South-East Queensland exhibit high concentrations of Zn, vanadium (V) and Cr (Preda and Cox, 2002). The investigators concluded that metal contents here were dependent on the presence of