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An Assessment of the Accumulation Potential of Pb, Zn and Cd by *Avicennia marina* (Forssk.) Vierh. in Vamleshwar Mangroves, Gujarat, India

Isaiah J. NIRMAL KUMAR[1], Poliyaparambil Ravi SAJISH[1], Rita NIRMAL KUMAR[2], George BASIL[1], Viyol SHAILENDRA[1]

[1]*Institute of Science and Technology for Advanced Studies and Research (ISTAR), P. G. Department of Environmental Science and Technology, Vallabh Vidya Nagar, Gujarat-388120, India; istares2005@yahoo.com*

[2]*N. V. Patel College of Pure and Applied Sciences, Department of Biological Science and Environmental Science, Vallabh Vidya Nagar, Gujarat-388 120, India; nvpas2009@gmail.com*

Abstract

The study deals with the accumulation of Pb, Zn and Cd in an important mangrove species, *Avicennia marina* (Forssk.) Vierh., in the Vamleshwar mangrove ecosystem, near Narmada estuary, West coast of Gujarat, India with height differences of 0.5, 1.5, 2.5 meters and carried out under field conditions during October, 2009. The site was located on 21°30´11.55´´ N latitude and 72°43´53.68´´ E longitude. Mangrove receives heavy metal pollution from upstream areas of Narmada estuary and highly populated settlements. However, little is known about the capacity of mangrove plants to take up and store heavy metals in them. Water, sediment and plant parts such as roots, stems and leaves were analyzed for finding the trace metal accumulation of different height groups by Inductive Coupled Plasma Analyser (ICPA). Amount of the content of metals found in the water, sediment and plant parts were in the order of Pb>Zn>Cd. The average contents of heavy metals in the waters were 57.83 mg l^{-1} for Pb, 3.89 83 mg l^{-1} for Zn and 0.42 mg l^{-1} for Cd. It was observed that the average contents of Pb (73.6 mg l^{-1}), Zn (8.1 mg l^{-1}) and Cd (0.73 mg l^{-1}) in the sediments were below the critical soil concentrations. The concentrations of heavy metals in different parts of *Avicennia marina* were in the order Roots>stem>leaf except for Cd, but Cd found higher in leaf. The ranges of the content of heavy metals in plants were 18.5-102.2 mg l^{-1} for Pb, 3.5-19.5 mg l^{-1} for Zn and 0.2-4.1 mg l^{-1} for Cd. The concentrations of all heavy metals in *Avicennia marina* except Pb were falling within the normal range and were much more in the plants have the highest height. The present study has shown the potential of *Avicennia marina* as a phytoremediation species for selected heavy metals in many mangrove ecosystems.

Keywords: *Avicennia marina* (Forssk.) Vierh., heavy metal accumulation, mangrove plant parts, sediments, Vamleshwar mangrove ecosystem

Introduction

Mangrove ecosystems are highly productive and play a vital role as a major primary producer within estuarine systems. The uniqueness of *A. marina* root system serves as a habitat and nursery area for many juvenile fish and crustaceans, which have both direct and indirect socio-economic significance and are of great importance to many scientific studies. They also provide erosion mitigation and stabilization for adjacent coastal landforms (Harty, 1997). Environmental pollution with toxic metals has been attracting considerable public attention over the past few decades. One of the major sources of heavy metal pollution is the mining and smelting of metalliferous ores (Li and Thornton, 2001). Besides the contamination from the weathering and leaching processes of mine tailings, untreated mine drainage also contributes large amounts of heavy metals to nearby streams and rivers. Heavy metals released into aquatic systems are generally bound to particulate matter, which eventually settle down and become incorporated into sediments. Surface sediment is the most important reservoir or sink of metals and other pollutants in aquatic environments. Sediment-bound pollutants can be taken up by rooted aquatic macrophytes and other aquatic organisms. Water pollution around the mining and smelting areas has been clearly demonstrated by the high concentrations of heavy metals in water, sediments, and aquatic organisms (Cardwell *et al.,* 2002; Demirezen and Aksoy, 2004; Samecka-Cymerman and Kempers, 2004). In recent years, there has been an ever-increasing interest in the study of metal-accumulating plants for environmental remediation application, termed as 'phytoremediation'. One method of phytoremediation is phytoextraction, which uses metal-accumulating plants to remove pollutants from contaminated soils by concentrating them in the harvestable aboveground parts (Salt *et al.,* 1998). For wastewater containing high concentrations of heavy metals, plant roots can also be used to absorb and adsorb

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pollutants, i.e., rhizofiltration. Aquatic plants can absorb bulk mineral salts either from the sediments via the root system, from the water phase by the leaves, or from both sources (Rai *et al.,* 2003).

In a plant-soil system, strong absorption and fixation of heavy metals by soil can easily cause residual accumulation in the soil, resulting in over-absorption of heavy metals by growing plants (Lian *et al*., 1999; Ravikumar *et al*., 2007). These plant products are harmful to the health of humans (Defew *et al*., 2005). The uptake of heavy metals by plants are passive, and its translocation from roots to other plant organs is generally low (Baker and Walker, 1990; De Lacerda and Abrao, 1986; Nirmal Kumar *et al*., 2008). Many studies have been carried out on various plants to determine its heavy metal accumulation capability in different aquatic and forest environments and vegetable crops (Nirmal Kumar *et al*., 2006, 2007, 2009; Silva *et al*., 2006; Yu *et al*., 2007;). There are several studies on heavy metal contamination in mangrove sediments and their effects on organisms but little is known about heavy metals uptake by mangrove plants (Seng *et al*., 1987; Ismail and Asmah, 1992). Therefore, an attempt was made to understand the metal phytoremediation potential of *A. marina* in a mangrove ecosystem at Vamleshwar, Gujarat, India, that would benefit in the wise-management and utilization of this ecosystem. The present study presents data on the concentrations of three metals (Pb, Zn and Cd) in water, sediment, and in leaves, stems and roots of *A. marina*.

Materials and methods

Sampling site

Sampling was conducted at Vamleshwar *A. marina* plantation, which is located 45km to west of Ankleshwar, Gujarat, India and facing the Arabian Sea at a latitude of 21°30′11.55′′ N and longitude of 72°46′53.68′′ E. The study area has various natural resources, vast array of biological diversity and coastal and riverine fishing activities (Fig. 1). The plant parts of different height groups viz., 0.5 m, 1.5 m and 2.5 m were collected in three replicates from the study site (n=10) during October 2009. The roots were carefully removed from the sediments while the leaves and stems were collected using a pair of scissors. The samples were immediately wrapped with an aluminium foil and labeled. All the samples were kept in a cooler box with ice at 4°C for storage during transportation and brought to the laboratory (Prica *et al*., 2007). After reaching the laboratory, root, stem and leaves samples were washed with double distilled water before storage. Water and sediment samples were collected from same sites where plant samples were collected. Soon after collection, the water samples were filtered through 0.45 µm millimeter filter and preserved in plastic bottles by the addition of a few drops of nitric acid. Sediment samples were preserved in air-dry plastic bags. The samples were labeled carefully and brought to the laboratory for further analysis.

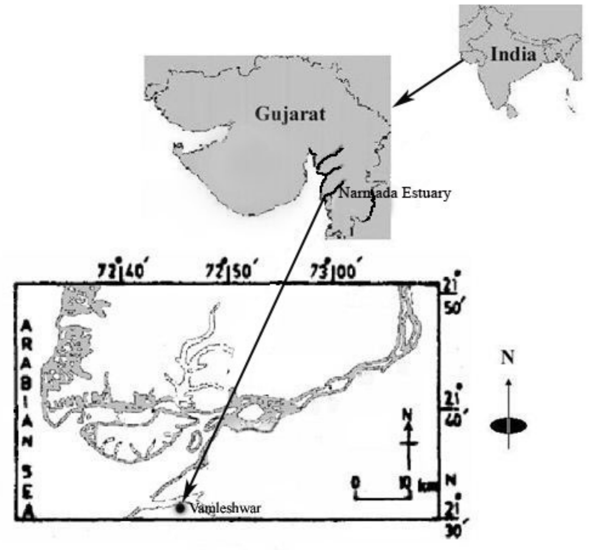

Fig. 1. Location of the study area

Analysis of plant parts, water and sediment for heavy metals

The plant parts of roots, stems and leaves samples were dried at 60°C for two days to achieve constant weight, homogenised and grounded to a fine powder. Samples then stored in plastic vials with labels and kept in desiccators. The samples of water, sediment and plant-parts were chemically examined for detection for Pb, Zn and Cd. Accurately 1 g of dry powder of each sample was weighed, and digested with con. HNO_3, H_2SO_4 and H_2O_2 (2:6:6) as prescribed by Saison *et al.* (2004). Towards the end of the digestion, the flasks were brought to near dryness. The solutions were made to 20 ml each in measuring cylinder with double distilled water and examined for Pb, Zn and Cd by Inductive Coupled Plasma Analyser (ICPA) (Perkin-Elmer ICP Optima 3300 RL, U.S.A) at Sophisticated Instrumentation Centre for Applied Research and Testing (SICART), Vallabh Vidyanagar, Gujarat, India. Mean values of triplicate of each sample of the water, sediment and plant samples were calculated and considered.

Statistical analysis

Pearson correlation coefficient analysis was done between metal-pairs in plants to check if differences exist between different metal combinations in either root, stem or leaf system. The products of the correlation coefficient (r) were evaluated as follows:

- 0-0.3: No correlation;
- 0.3-0.5: Low correlation;
- 0.5-0.7 Medium correlation;
- 0.7-0.9 High correlation;
- 0.9-1.0 Very high correlation.

Further the comparison of the concentration of an element in an aquatic organism with that of the same element in the water in which the organism lives was made. This is the ratio between the concentration of the element in the organism and that of in the water, which is known as Concentration Factor (De Bortoli *et al*., 1968).

Further the data was analyzed using ANOVA to detect if any significant differences in means of each heavy metal exist between mangrove sediments, roots, stems and leaves and of different heights. Significance value was set at 5%.

Results and discussion

Heavy metal accumulation in the mangrove sediments, water and mangrove plant parts

The average concentration of Pb (73.6 mg l^{-1}) was higher in the sediments followed by Zn (8.1 mg l^{-1}), and Cd (0.73 mg l^{-1}) (Fig. 2A-2C). like sediment the concentration of Pb (57.83 mg l^{-1}) in water was greater than the other two elements (Zn-3.89 mg $l^{-1}$and Cd-0.42 mg l^{-1}) (Fig. 2). However, when compared to the critical soil concentrations, the total concentrations for all selected heavy metals present in the sediments were below the critical soil concentration values (Alloway, 1990) (Tab. 1). Meanwhile, the comparison of the total concentrations of the selected heavy metals in the sediments with those from other countries showed that the concentration of Cd in this study was greater than those measured in Buloh River and Khatib Bongsu River at Singapore by Cuong *et al*. (2005), Brisbane River, Australia by Mackey *et al*. (1992) and Mai Po river, Hong Kong by Ong Che (1999). The values of the ratio between element concentrations in the sediments and those in the water were low for Pb (1.27) where as that of Zn was observed high (2.08) (Tab. 2).

Heavy metal concentrations were detected in the mangrove parts prove that Pb, Zn and Cd were distributed in all three parts of *A. marina*. From the observations, *A. marina* accumulated high concentration of heavy metals in the root system compared to the other parts of plant except Cd which found high in leaves followed by root and stem. Greater accumulation was observed in the plant parts of tallest plant group i.e. 2.5 m. The average content of Pb in leaf, stem, and root were 48.64, 21.94 and 91.07 mg l^{-1} while for Zn 11.24, 5.78 and 15.53 mg l^{-1} whereas for Cd 2.40, 0.77 and 1.70 mg l^{-1} respectively (Fig. 2) The average content of the elements in the plants declined according to this sequence: Pb>Zn>Cd.

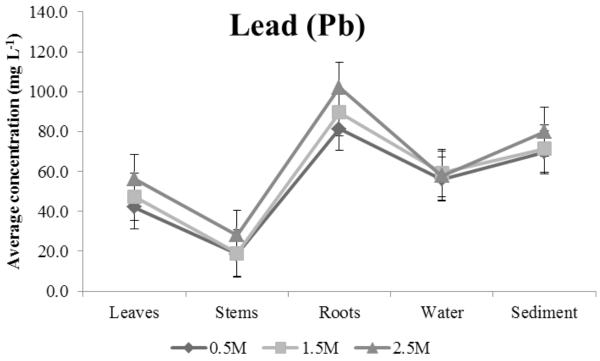

Fig. 2A.

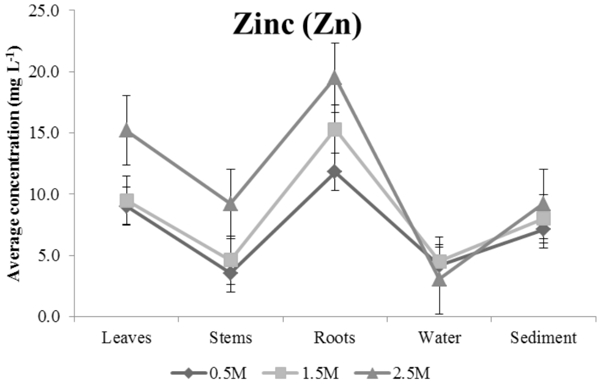

Fig. 2B.

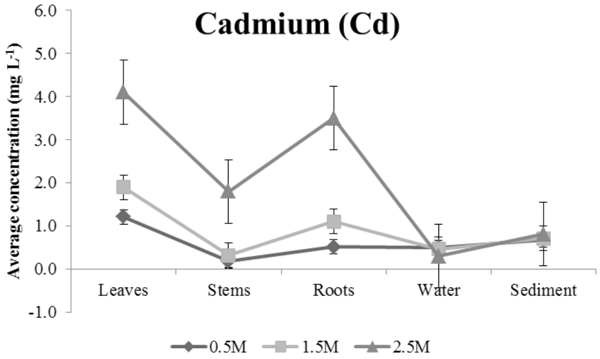

Fig. 2C.

Fig. (2A-2C). The mean concentrations of Pb, Zn and Cd in the roots, stems, leaves, water and sediments of *A. marina* (*n=3*) plantation of different height groups viz., 0.5 M, 1.5 M and 2.5 M

Tab. 1. The total concentrations of heavy metals (mg L^{-1}) in mangrove sediments of Vamleshwar mangrove ecosystem (present study) relative to other countries. Critical soil concentrations follow Alloway (1990)

	Pb	Zn	Cd	References
Vamleshwar Mangrove Ecosystem, Gujarat, India	73.6±4.72	8.1±2.94	0.73±0.153	Present study
Singapore (Buloh River)	12.28±5.18	51.24±39.97	0.181±0.189	Cuong *et al.* (2005)
Singapore (Khatib Bongsu River)	30.98±6.16	120.23±13.90	0.266±0.171	Cuong *et al.* (2005)
Australia (Brisbane River)	20.1-81.9	40.8-144.0	<0.1-1.9	Mackey *et al.* (1992)
Hong Kong (Mai Po)	161.6-219.8	277.2-321.2	0.5-0.6	Ong Chee (1999)
Critical Soil Concentrations	100-400	70-400	3-8	Alloway (1990)

Tab. 2. Elemental concentration ratios between sediments and water

	Sediment (mg l^{-1})	Water (mg l^{-1})	Sediment/Water
Pb	73.6	57.83	1.27
Zn	8.1	3.89	2.08
Cd	0.73	0.42	1.74

The critical ranges of heavy metals in plants were 30-300 mg l^{-1} for Pb, 100-400 mg l^{-1} for Zn and 10-30 mg l^{-1} for Cd. The concentrations of all heavy metals in *A. marina* except Pb were within the normal range in the present study.

Statistical analysis

The concentration factor (C. F) for all three heavy metals and that of different components of *A. marina* also were evaluated (Tab. 3). The mean C. F. value of elements in the different parts declined according to this sequence: Cd> Zn > Pb. The mean C. F. for the various elements calculated for root is rather high followed by leaf and stem (Tab. 3). The concentration distribution in plant parts like leaves, stems and roots may vary depending on the concentration of heavy metals in the sediment, height of the plants, the types of heavy metals and also the tolerance of the species and its parts towards the heavy metals. The present study is well corroborated with works by De Lacerda and Abrao (1986); Baker and Walker (1990).

Tab. 3. Concentration factors calculated for different parts of *A. marina* and elements

	Pb	Zn	Cd	Mean
Leaf	0.84	2.89	5.71	3.15
Stem	0.38	1.49	1.83	1.23
Root	1.57	4.0	4.05	3.21
Mean	0.93	2.79	3.86	
SD	0.60	1.26	1.95	

The output of Pearson correlation coefficient (r) analysis on combinations of different metal-pairs which are present together in either roots, stems or leaves of *Avicennia marina* showed that a high +ve correlation (r=0.6-0.9) between all the metal-pairs analyzed (Tab. 4) except in the root system.

Tab. 4. Pearson correlation coefficient between concentrations of heavy metal pairs in root, stem and leaf systems of *A. marina*

Analysis metal-pair	Root system	Stem system	Leaf system
Zn × Pb**	0.655	0.844	0.635
Cd × Pb**	-0.982	0.990	0.980
Zn × Cd**	-0.500	0.911	0.775

** high correlation (r=0.6-0.9)

The ANOVA also showed marked distinction of the heavy metals (Pb, Zn and Cd) concentrations between mangrove sediments and the roots of *A. marina* (Pb, p=0.01; Zn, p=0.005; Cd, p=0.01).

The study showed the transport mechanism of metals from sediment to plant and their accumulation in various parts of the plant. The transport mechanism and accumulation pattern of heavy metals can be elaborated as follows: sediment>root system>stem system>leaf system.

Conclusions

This study has shown that *A. marina* possesses the capacity to take up selected heavy metals via its roots and storing in its leaves without any sign of injury. As it grows more aged, its capability of accumulating heavy metals is also increasing much fold. This suggests the potential of *A. marina* as a phytoremediation species for many mangrove ecosystems. The luxuriant growth of *A. marina* in comparison to other mangrove species is evident to its adaptability even under polluted conditions.

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