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Analysis of Heavy Metals Accumulation in Mangroves and Associated mangroves Species of Ennore Mangrove Ecosystem, East Coast India

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Abstract

Background/Objectives: This study is to collect the samples of true mangrove plant, associated mangrove plants, water and sediments from Ennore Mangrove Ecosystem and the samples are analyzed for heavy metals accumulation. **Methods/ Statistical Analysis**: The water, sediment and plant materials were collected at 6 locations. After the collection, the plant materials were washed with distilled water and they were dried and acid digested. Further the samples were subjected to analysis of heavy metals by flame atomic absorption spectrophotometer. Triplicate samples were analyzed and their results were expressed in ppm. The statistical analysis ANOVA (Analysis of Variance) and DMRT (Duncan Multiple Range Test) were used. **Findings**: The maximum concentrations of metals were accumulated (lead-20.93±0.26 ppm/l in water and 48.5±1.44 ppm/g in sediments) in station 4, 5 and minimum concentration (zinc -2.95±0.25 ppm/l in water and 4.36±0.10 ppm/g in sediment) was observed in station 5. In overall average accumulation of heavy metals like Pb (6.09±4.59 ppm/g) > Zn (4.35±3.22 ppm/g) > Cd (3.78±2.80 ppm/g) > Hg (2.84 ± 2.70 ppm/g) > Cr (2.76±2.90 ppm/g) > Cu (0.58 ±0.42 ppm/g) found in the *Avicennia marina* followed by Pb (4.19±3.13 ppm/g) > Zn (4.12±3.32 ppm/g) > Cd (3.78±2.79 ppm/g) Cr (2.47±1.91 ppm/g) Hg (1.89±1.61ppm/g) > Cu (1.27±1.20 ppm/g) in the *Suaeda nudiflora* and Pb (4.39±3.23 ppm/g) > Zn (3.77±2.99 ppm/g) > Cd (2.39±1.86 ppm/g) > Cr (1.75±1.34 ppm/g) Hg (0.76±0.74 ppm/g) > Cu (0.50±0.40 ppm/g) in the *Sesuvium portulacastrum*. The metal concentration of the water and sediments were significantly ($p<0.05$) varied and in plants, lead (Pb) were significantly varied ($p<0.05$) between selected plants parts then the other metals like Hg, Cr, Cd, Cu and Zn were not significant. **Application/Improvements:** Heavy metals contamination was observed in all samples. The mangroves accumulated more concentration than associated mangroves, therefore the *Avicennia marina* is suitable candidate for bioaccumulator and recommended for phytoremediation.

Keywords: Accumulation, Ecosystem, Ennore, Heavy Metals, Mangroves, Phytoremediation

1. Introduction

Mangroves are salt tolerant plants, they are dominated in the tropical and subtropical foreshore and seashore regions and they are also have special adaptation to survival of extreme salt conditions in the brackish water environment like waterlogged and anaerobic soil conditions. Mangrove wet lands acted as a good nursery ground for variety of commercially important organisms[1]. In addition, the mangrove ecosystem

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play an important role in providing goods and services to humans, which includes aquaculture, forestry, shoreline protection from erosion, burning wood and house hold materials and other products like honey, wax and essence[2]. The Ennore Mangrove Ecosystem (80°25'E; 13°14'N) comprises of shallow water body of river mouth with coastal wet lands and low barrier islands called backwaters. This ecosystem is flooded under high tidal fluctuations and its opens in to the Coromandel cost of Bay of Bengal. The total area of the Ennore creek is 2.25 sq km and it has nearly 400 m wide. In north end it is connected to the Pulicat Lake and the southern end connected by Kosasthalaiyar River[3]. Today most of the coastal ecosystems are threaten by heavy metal pollution due to the industrial effluents, which leads to heavy metals accumulation in the coastal ecosystems. These are harmful to the organisms and human beings via the food chain[4].

The mangroves are exposed to heavy metal pollution due to the manmade activities like mining, metal smelting, burning of fossil fuels and agricultural pesticide production and as well as domestic and industrial sewage[5]. The mangrove sediments have high metal binding capacity because sediments have anaerobic nature with richness of sulphide content, which can easily catch the metals and increase the concentration of metals in the mangrove sediments, therefore this availability of metal concentration leads to bioaccumulation in the plant tissues[6].

However the heavy metal pollution can damage both biodiversity and ecosystem through the tendency of bioaccumulation in the food chain of marine biota. The heavy metal bioaccumulation is directly proportional to the concentration of metals in the surrounding environment like water, sediments and period of time exposure, in addition other factors like salinity, pH, hardness and temperature are responsible for accumulation[7]. The mangrove wetlands are frequently subjected to heavy metal pollution by anthropogenic sources because they are located intertidal areas of coastal region[8]. Mangroves have ability to tolerate high levels of heavy metals[9] particularly the *Avicennia* species have capacity to accumulate more amount of heavy metals than other mangrove species[10].

The heavy metals pollution in the coastal area and its bordering ecosystem of mangroves are subjected to serious threat for environmental safety[11]. Numerous studies revealed that the accumulation potential of heavy metals in water, sediment and commercial faunal species but heavy metals accumulation studies of mangroves and associated mangroves species of Ennore Mangrove Ecosystem are rare. Therefore, an attempt was made to understand the bioaccumulation potentials of mangrove species *Avicenia marina* and associated mangrove species *Sesuvium portulacastrum* and *Suaeda nudiflora* from Ennore Mangrove Ecosystem. The current study aims to analysis of heavy metals like Cr, Cu, Cd, Hg, Pb, and Zn in the leaves stems and roots of *Avicenia marina*, *Sesuvium portulacastrum* and *Suaeda nudiflora*. In this study would supports to understand the bioaccumulation potentials of mangrove and its management of the Ennore Mangrove Ecosystems.

2. Materials and Methods

2.1 Study Area and Sampling Stations

The Ennore Mangrove Ecosystem (Latitude 13 ° 15 ° N and Longitude 80 ° 19 ° E) extends 4 sq.km areas; it is situated north eastern part of Chennai city about 24 km distance. This ecosystem bounded in the mouth of the river Kosasthalaiyar along the Bay of Bengal. It is an opening for drains the surplus water from the Poondi reservoir, during the non monsoon period the depth exceeds up to 5 km. This ecosystem fed by Buckingham canal and Kosasthalaiyar River. The Ennore Mangrove Ecosystem (Ennore creek) flows from the west to east and open in to the Bay of Bengal (Figure 1and 2).

Six sampling stations were fixed along the Ennore Mangrove Ecosystem. The sampling locations were selected based on the properties of physicochemical parameters and the source of contaminations. The sampling locations were SL1-Mouth (13°13'56.6"N 80°19'43.4"E), SL2- Houses area (Out let of domestic sewage) (13°13'25.0"N 80°19'09.4"E), SL3- Moola Odai (Near NCTPS) (13°13'55.5"N 80°18'47.8"E), and SL4-Valluru Thermal Power Station Out let area (13°13'53.2"N 80°18'45.5"E), SL5-Mangrove vegetation (13°13'24.7"N 80°18'57.5"E) and SL6-Boat Shed (13°13'19.3"N 80°19'08.5"E). The water, sediment and plant samples were collected from six different locations of the Ennore Mangrove Ecosystem during the post monsoon month of February 2014.

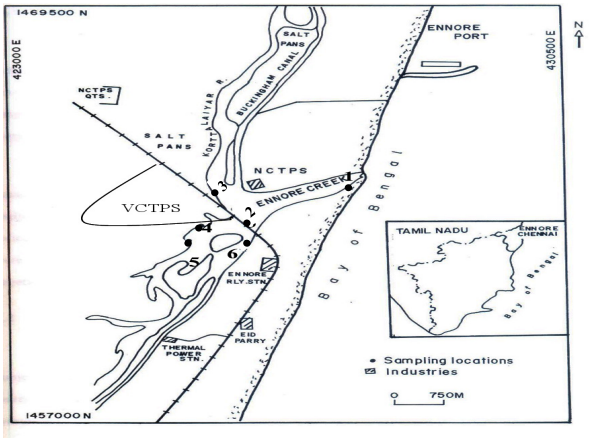

Figure 1. Map showing the sampling points of the study area at Ennore Mangrove Ecosystem.

Figure 2. Map showing the sampling points of the study area at Ennore Mangrove Ecosystem (Satellite view).

2.2 Sample Preparation and Analysis

2.2.1 Water Samples

25 ml of water samples were collected and filtered by using Whatmann No. 1 (0.45 µm) filter paper and the pH was adjusted to 3.5 with help of 0.1 N of HCl. Then the nitric acid digestion procedure was followed[12]. A blank was also digested using the de-ionized water as a reference material.

2.2.2 Sediment Samples

The collected soil samples were oven dried at 105ºC and homogenized by using mortar and pestle according to normalize the grain size. Then the homogenized samples were subjected sieve through a 250 µm pore size and it was store in the plastic bottles for further study. Finally the sieved sediment samples were subjected to perchloric acid digestion[13].

2.2.3 Plant Samples

The fresh plant materials like mature leaves, stems and roots were collected from selected mangrove species of *Avicennia marina* and associated mangrove species *Suaeda nudiflora* and *Sesuvium portulacastrum*. The roots were carefully collected after removing the sediments. All the samples were labelled and stored in cool box with ice at 4°C and transported to the laboratory and the leaves bark and root samples were thoroughly clean the debris with glass distilled water and then allowed to oven dry at 60°C for 24 hours[14].

2.2.4 Heavy Metal Analysis

The acid digested triplicates samples were analyzed for heavy metals (Cr, Cu, Cd, Hg, Pb and Zn) accumulation by Atomic Absorption Spectrophotometer (AAS - Perkin-Elmer AA700)[12] and the concentrations were expressed in ppm.

2.3 Statistical Analysis

Analysis of Variance (ANOVA) and Duncan Multiple Range Test (DMRT) were used to analysis of selected heavy metals. The differences of metal concentrations among the plant parts were studied. The statistical analyses were carried out through SPSS 15.0.

3. Results and Discussion

3.1 Heavy Metal Concentration in Mangrove Water and Sediment

Heavy metals concentrations of water samples were represented in the Table 1 and Figures 3 and 4. The concentration of lead in water was highest in station 4 (20.93±0.26 ppm/l) while the concentration of the following metals like chromium (13.56±0.16 ppm/l), mercury (10.43±0.20 ppm/l), cadmium (8.93±0.15ppm/l) and copper (4.92±0.30 ppm/l) were highest in the same station 4 except the concentration of zinc, it was high in station 5 (2.95±0.25 ppm/l). Average concentration of heavy metal accumulation in the water samples were found in the following decreasing order Pb (18.12 ± 2.15 ppm) > Cr (10.24 ±2.44 ppm) > Hg (7.76 ± 2.84 ppm) > Cd (6.82 ± 1.72 ppm) > Cu (2.94 ± 1.21 ppm) > Zn (2.0±0.50 ppm) in all station of Ennore Mangrove Ecosystem. The highest concentration was observed for lead (20.93±0.26 ppm/l) in station 4 and lowest was observed for zinc (2.95±0.25 ppm/l) in station 5. In station wise the metal concentration were found in the following sequential order 4 > 5 > 3 > 2 > 6 > 1. In water samples, most of the metals were accumulated in high concentration during monsoon

Table 1. Heavy metal concentrations of water and sediment samples from Ennore Mangrove Ecosystem

Sampling Locations	Sample Name	Heavy metal concentrations (ppm/l for water and ppm/g for sediment)					
		Hg	Cr	Cd	Pb	Cu	Zn
1	Water	5.05±0.12^{b}	8.45±0.08^{b}	4.56±0.06^{a}	19.84±0.05^{d}	1.41±0.20^{a}	2.04±0.01^{a}
	Sediment	6.56±0.19^{a}	2.95±0.28^{a}	3.60±0.17^{a}	11.6±0.46^{a}	1.94±0.03^{a}	0.94±0.09^{a}
2	Water	8.65±0.02^{c}	10.9±0.57^{c}	6.99±0.00^{a}	17.55±0.03^{bc}	2.65±0.05^{c}	1.45±0.05^{a}
	Sediment	7.02±0.00^{b}	3.13±0.04^{a}	4.05±0.02^{b}	13.95±0.08^{b}	2.35±0.08^{b}	1.04±0.06^{a}
3	Water	9.04±0.02^{c}	11.5±0.98^{c}	7.56±0.03^{a}	18.6±0.34^{b}	3.14±0.04^{d}	1.78±0.34^{a}
	Sediment	7.69±0.06^{c}	4.95±0.07^{b}	4.56±0.09^{c}	15.56±0.03^{b}	1.94±0.02^{a}	1.56±0.02^{b}
4	Water	10.43±0.20^{d}	13.56±0.16^{d}	8.93±0.15^{a}	20.93±0.26^{e}	4.92±0.30^{e}	1.94±0.02^{a}
	Sediment	8.56±0.03^{d}	5.35±0.02^{bc}	5.13±0.07^{d}	32.6±0.80^{c}	3.36±0.11^{c}	2.36±0.04^{c}
5	Water	9.97±0.26^{d}	10.5±0.57^{c}	7.95±0.75^{a}	16.9±0.49^{b}	3.45±0.02^{d}	2.95±0.25^{b}
	Sediment	10.54±0.05^{f}	10.3±0.69^{d}	8.95±0.25^{f}	48.5±1.44^{d}	5.95±0.11^{e}	4.36±0.10^{d}
6	Water	3.45±0.31^{a}	6.55±0.19^{a}	4.95±0.11^{a}	14.9±0.51^{a}	2.11±0.00^{a}	1.84±0.17^{a}
	Sediment	9.05±0.03^{e}	5.98±0.04^{c}	6.34±0.04^{e}	32.9±0.17^{c}	5.45±0.08^{d}	2.55±0.02^{c}

(The values were average of triplicate samples with standard error and dissimilar alphabets are significant at 5% level).

season. This might be attributed by rain water runoff through river during the monsoon periods[15].

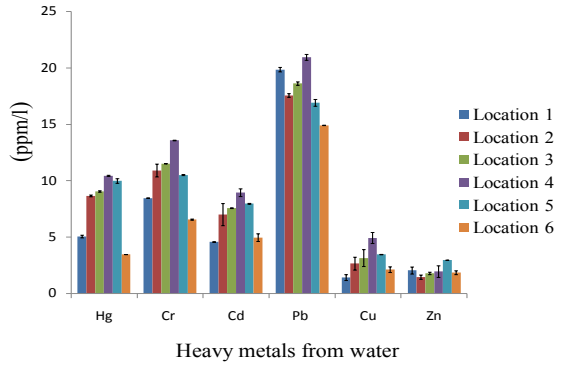

Figure 3. Heavy metal concentrations of water from Ennore Mangrove Ecosystem.

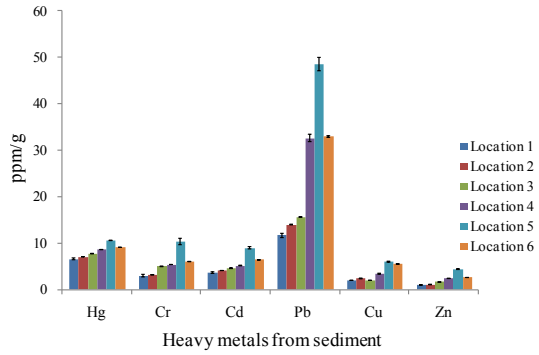

Figure 4. Heavy metal concentrations of sediment from Ennore Mangrove Ecosystem.

However, in the sediments, the concentration of lead (48.5±1.44 ppm/g) was highest in station 5 and the remaining studied metals like mercury (10.54±0.05 ppm/g), chromium (10.3±0.69 ppm/g), cadmium (8.95±0.25 ppm/g), copper (5.95±0.11ppm/g) and zinc (4.36±0.10 ppm/g) were also high in same station. The heavy metals concentration of the sediments were found in the following order Pb > Hg > Cr > Cd > Cu > Zn. In station wise maximum concentration of heavy metals were observed in the order of 5 > 6 > 4 >3 > 2 > 1. The arsenic and chromium concentrations were high in water samples and arsenic, cadmium and lead concentrations were high in the sediment samples of Ennore estuary during the post-monsoon season, this sediment concentration was attributed by availability and settlement of heavy metals from the water[16]. The mangrove sediments act as a sink for heavy metals accumulation because sediments have ability to capture of heavy metals from water[17].

In sediments, average concentration of heavy metals accumulated from Ennore Mangrove Ecosystem were found in the following sequential order of Pb (25.85±14.55 ppm) > Hg (8.23±1.46 ppm) > Cr (5.44 ± 2.67 ppm) > Cd (5.43 ± 1.96 ppm) > Cu (3.49 ± 1.78 ppm) > Zn (2.13±1.27 ppm). The high concentrations of metals were accumulated in the Ennore seacoast during summer season than monsoon season, the low metal concentration depending upon the fresh water inflow through rain fall and discharges of surplus water from the Poondi reservoir and high concentration depends upon the evaporation of

water by solar energy. The zinc and lead concentrations were high in the sediment when compared to copper and cadmium concentrations. The concentrations of heavy metal accumulation are not uniform in the water[18].

Heavy metals (Hg, Cr, Cd, Pb, Cu and Zn) concentration of water and sediments were significantly ($p<0.05$) varied between the selected locations of the Ennore Mangrove Ecosystem, while the difference was significant at 5% level. It is observed from Table 1, that all the considered metals showed higher concentration in water and sediments. The four heavy metals (arsenic, cadmium, chromium and lead) concentration of the sediment samples was maximum in the Ennore, this concentration fluctuation depends upon the discharges of untreated industrial effluents[19].

The differences in distribution of metals in different locations can be attributed to heavy metals originating from urban runoff and brackish water from Buckingham canal, discharges of sewage and domestic garbage dumps, industrial effluents, boating activities and agricultural insecticides and fungicides through inflow of freshwater from dramatically increase its concentration in intertidal water and sediments. In Ennore Mangrove Ecosystem sediments accumulated more heavy metals than the water. The wetland waters and sediments are heavily contaminated by heavy metals pollution and then it accumulates to the tissues of fauna and flora. However they are biomagnified and enter in to the marine food chains[20]. The mangrove sediments are fine particles of clay and silt tend to accumulate more amounts of heavy metals[21]. Hence their region is necessary to suitable treatment methods for removal of metals in the water and sediments by suitable bioremediation methods[22].

3.3 Heavy Metal Distribution in A. Marina

Heavy metal concentration of the *Avicennia marina* plant parts (leaf, stem and root samples) were shown in the Table 2 and Figures 5 to 7. Among the six metals tested for of A. *marina* plant parts from Ennore Mangrove Ecosystem in leaf found that lead concentration was the highest (5.19±4.0 ppm/g) and zinc (3.77±2.92 ppm/g) followed by cadmium (3.36±2.60 ppm/g) chromium (1.44±1.11ppm/g), mercury (0.89±0.69 ppm/g) and copper (0.59±0.46 ppm/g), respectively, in stem found that lead concentration was the highest (5.82±4.55 ppm/g) and zinc (4.36±3.38 ppm/g) followed by mercury (3.95±3.06 ppm/g), cadmium (3.6±2.79 ppm/g), chromium (1.74±1.35 ppm/g), and copper (0.63±0.49 ppm/g), respectively and in root samples found that lead concentration was the highest (7.26±5.63 ppm/g) and chromium (35.11±3.96 ppm/g) followed by zinc (4.91±3.80 ppm/g), cadmium (4.37±3.39 ppm/g), mercury (3.69±2.86 ppm/g) and copper (0.51±0.39 ppm/g), respectively. The Ennore estuary zinc levels were more in water as well as in tissues of organism[18]. The Pb, Zn and Cu concentrations of *A. marina* roots were ranged in the following order (2.89 ppm to 15.88 ppm, 20.57 ppm to 107.30 ppm and 16.29 ppm to 45.21 ppm), stem of same species were ranged (1.11 ppm to 15.51 ppm, 15.00 ppm to 90.20 ppm and 13.89 ppm to 39.14) and leaf of the same species, the concentration were ranged (1.58 ppm to 13.77 ppm, 13.43 ppm to 61.34 ppm and 13.23 ppm to 28.05 ppm) during monsoon[11]. Considerably Zn and Cu concentrations were high in the mangrove plant parts while Pb and Cr were found in concentration. Hence the mangroves plays a important role for reducing the heavy metals transport to the adjacent ecosystems like estuarine and marine ecosystems, since it acts as a sinks for heavy metals and also it have a tendency for immobilize the metals [23].

The sequence of metals in the stations were represented in 4 > 5 > 6 > 3 of *Avicenia marina*. However, the sequences were the same for *Sesuvium* portulacastrum and the accumulation pattern in Suaeda *nudiflora* showed little variation indicating the following pattern 4 > 6 > 5 > 3. In compare to other halophytes mangrove species, the *Avicennia marina* showed higher accumulation of the heavy metals[24]. The following concentration of heavy metals accumulated in the plant parts of A. *marina*, that is Pb > Zn > Cu > Cd > Hg > Cr > Cu. As. Comparison of leaf and stem samples of *A. marina,* the roots accumulated high concentration of heavy metals. The higher amount of heavy metal accumulation was recorded at sampling location of 4 followed by sampling locations of 5, 6 and 3 of mangrove plant and associated mangrove plants from Ennore Mangrove Ecosystem. Plants have universal protective mechanism of stress particularly in the metals accumulation[25].

Bioaccumulations of heavy metals in mangrove tissues are provided one of the indicators and used to monitoring the coastal heavy metals pollution in tropical and subtropical region[26].

Findings of the study reveals that maximum concentration of heavy metals accumulated in the following root > stem > leaf of *A. marina*. The heavy metals such as Cu,

Table 2. Heavy metal concentrations of Mangroves *Avicenia marina* plant parts collected from Ennore Mangrove Ecosystem

Sampling Locations	A. marina plant parts	Heavy metals (Concentrations in ppm/g)					
		Hg	Cr	Cd	Pb	Cu	Zn
1	Leaf	-	-	-	-	-	-
	Stem	-	-	-	-	-	-
	Root	-	-	-	-	-	-
2	Leaf	-	-	-	-	-	-
	Stem	-	-	-	-	-	-
	Root	-	-	-	-	-	-
3	Leaf	1.35±0.10[a]	2.16±0.08a	5.03±0.05[a]	6.95±0.25[a]	0.91±0.01[a]	5.68±0.10[a]
	Stem	5.94±0.75[a]	2.65±0.19[a]	5.47±0.04[a]	7.95±0.25[a]	0.98±0.05[a]	6.57±0.32[a]
	Root	5.47±0.06[a]	7.65±0.40[a]	6.57±0.58[a]	10.65±0.12[a]	0.75±0.09[a]	7.35±0.15[a]
4	Leaf	1.42±0.11[a]	2.10±0.06[a]	5.02±0.28[a]	8.76±0.03[d]	0.89±0.06[a]	5.75±0.15[a]
	Stem	5.98±0.43[a]	2.60±0.08[a]	5.40±0.16[a]	9.83±0.19c	0.95±0.04[a]	6.63±0.05[a]
	Root	5.50±0.14[a]	7.71±0.29[a]	6.60±0.17[a]	11.21±0.06[b]	0.79±0.05[a]	7.40±0.23[a]
5	Leaf	1.30±0.02[a]	2.21±0.06[a]	5.07±0.17[a]	8.02±0.07[c]	0.90±0.03[a]	5.60±0.10[a]
	Stem	5.92±0.06[a]	2.61±0.05[a]	5.36±0.05[a]	8.98±0.01[b]	0.96±0.06[a]	6.48±0.04[a]
	Root	5.40±0.14[a]	7.62±0.04[a]	6.53±0.09[a]	10.86±0.10[a]	0.77±0.04[a]	7.38±0.11[a]
6	Leaf	1.32±0.06[a]	2.18±0.10[a]	5.08±0.05[a]	7.41±0.06[b]	0.88±0.01[a]	5.63±0.05[a]
	Stem	5.90±0.37[a]	2.63±0.13[a]	5.40±0.28[a]	8.16±0.00[a]	0.91±0.06[a]	6.51±0.14[a]
	Root	5.77±0.37[a]	7.64±0.08[a]	6.56±0.02[a]	10.88±0.06[a]	0.76±0.12[a]	7.37±0.06[a]

The '–'denotes absence of mangrove plants in selected sampling locations

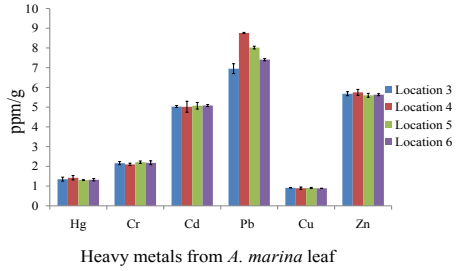

Figure 5. Heavy metal concentrations of mangroves *A. marina* leaf collected from Ennore Mangrove Ecosystem.

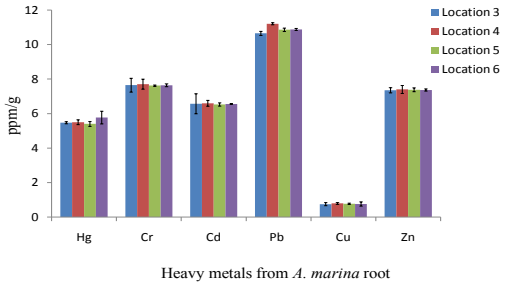

Figure 7. Heavy metal concentrations of mangroves *A. marina* root collected from Ennore Mangrove Ecosystem.

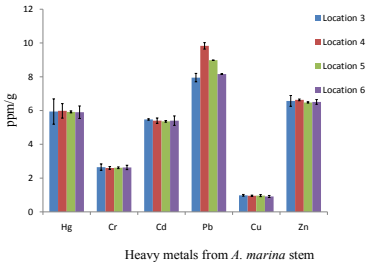

Figure 6. Heavy metal concentrations of mangroves *A. marina* stem collected from Ennore Mangrove Ecosystem.

Zn, Pb, Fe, Mn and Cd were primarily tend to accumulate in root tissues, rather than in the other plant parts while it was lower than sediments[27]. In mangrove plants, more amount of metals accumulated in the fine roots than in the leaf because the leaf concentration reduced by leaf litter fall and also the metal concentration was high in the fine roots when compare to sediment[8].

Bioaccumulations of heavy metals in mangroves are depending upon the species and tissue types for example lead was selectively concentrated in bark and wood of

mangroves whereas zinc and copper reach their highest concentrations in young leaves[26].

The high concentrations of essential metals were accumulated in mature mangroves whereas high concentrations of non-essential metals accumulated in mature mangroves reside in the industrially polluted sites[28]. The Cu concentration was high in the *Avicennia marina* and *Rhizophora mucronata* due to the industrial effluents and anthropogenic activities. Bioaccumulation coefficient of heavy metals were found in the following order of Cu > Zn > Al > Co, Cr > Fe > Mn > Mg in the *Avicennia marina*[29]. The zinc concentration in the *Avicennia officinalis* indicates toxic level, which leads to the food chain contamination and the stem accumulates Zinc above the permissible level[30]. The lead and zinc concentration were high in the *Avicennia alba* than *R.mucronata*[31]. In mangrove leaf samples zinc accumulated more concentrations followed by lead and chromium then copper[32] because zinc is highly mobile metal, while it can easily accumulate in the leaves[12]. Based on the previous studies and accumulative behavior the grey mangroves *Avicennia marina* plays a vital role for removal of heavy metals from polluted coastal environment[33].

3.4 Heavy Metal Distribution in *Sesuvium portulacastrum* and *Suaeda nudiflora*

The heavy metals concentration of *Sesuvium portulacastrum* plant parts (leaf, stem and root samples) were shown in the Table 3 and Figures 8 to 10. The following concentration of heavy metals accumulated in the leaf of *Sesuvium portulacastrum* from Ennore Mangrove Ecosystem was Pb (3.98±3.12) > Zn (2.44±1.89) > Cd (1.65±1.28) > Cr (1.29±1.00) > Hg (0.31±0.24) > Cu (0.31±0.24). However, apparently the concentration of stem samples as follows Pb (4.50±3.48) > Zn (4.41±3.42) > Cd (2.70±2.09) > Cr (1.92±1.49) > Hg (0.69±0.53) > Cu (0.54±0.42) and the root of same species were found in Pb (4.68±3.63) > Zn (4.46±3.46) > Cd (2.83±2.19) > Cr (2.05±1.59) > Hg (1.27±0.99) and Cu (0.64±0.50) respectively (Table 4). The heavy metals accumulation was found in the following order of Zn > Cu > Pb in the root, stem and leaf samples of mangroves and associated mangrove species. In the present study reveals that significant variations was observed

Table 3. Heavy metal concentrations of the plant parts of *Sesuvium portulacastrum* collected from Ennore Mangrove Ecosystem

Sampling Locations	S. portulacastrumplant parts	Heavy metals (Concentrations in ppm/g)					
		Hg	Cr	Cd	Pb	Cu	Zn
1	Leaf	-	-	-	-	-	-
	Stem	-	-	-	-	-	-
	Root	-	-	-	-	-	-
2	Leaf	-	-	-	-	-	-
	Stem	-	-	-	-	-	-
	Root	-	-	-	-	-	-
3	Leaf	0.46±0.06[a]	1.94±0.25[a]	2.46±0.17[a]	5.45±0.60[a]	0.45±0.13[a]	3.56±0.38[a]
	Stem	1.02±0.04[a]	2.64±0.17[a]	4.06±0.29[a]	6.76±0.46[a]	0.78±0.12[a]	6.56±0.25[a]
	Root	1.66±0.16[a]	3.10±0.22[a]	4.27±0.15[a]	7.34±0.18[a]	0.99±0.00[a]	6.50±0.79[a]
4	Leaf	0.49±0.12[a]	1.97±0.13[a]	2.51±0.26[a]	6.94±0.37b	0.50±0.08[a]	3.88±0.04[a]
	Stem	1.09±0.06[a]	2.99±0.57[a]	4.08±0.27[a]	6.82±0.34[a]	0.89±0.06[a]	6.72±0.40[a]
	Root	2.04±0.46[a]	3.16±0.09[a]	4.39±0.22[a]	6.94±0.34[a]	0.98±0.06[a]	6.89±0.98[a]
5	Leaf	0.47±0.04[a]	1.95±0.11[a]	2.48±0.16[a]	5.81±0.10[a]b	0.46±0.04[a]	3.60±0.02[a]
	Stem	1.01±0.29[a]	2.96±0.55[a]	4.04±0.57[a]	6.73±1.15[a]	0.80±0.00[a]	6.61±0.86[a]
	Root	1.98±0.23[a]	3.01±0.59[a]	4.18±0.10[a]	6.93±0.53[a]	0.96±0.17[a]	6.70±0.40[a]
6	Leaf	0.48±0.09[a]	1.93±0.04[a]	2.47±0.08[a]	5.70±0.17[a]b	0.48±0.11[a]	3.61±0.06[a]
	Stem	1.03±0.11[a]	2.95±0.23[a]	4.05±0.02[a]	6.72±0.41[a]	0.81±0.12[a]	6.60±0.23[a]
	Root	1.96±0.26[a]	3.04±0.31[a]	4.16±0.09[a]	6.90±0.51[a]	0.95±0.31[a]	6.71±0.57[a]

The '–'denotes absence of associated mangrove plants in selected sampling locations
(The values were average of triplicate samples with standard error and similar alphabets are not significantly different by DMRT (Drunken Multiple Range Test) at 5% level).

in the concentration between species and stations ($p < 0.01$) however it was confirm that different species have different ability of accumulation and it was useful for bioremediation[11].

The heavy metal abundance in leaf of *Suaeda nudiflora* have the following sequential order Pb (3.78±2.93) > Cd (3.78±2.92) > Zn (3.08±2.38) > Cr (2.90±2.25) > Hg (1.25±0.98) and Cu (0.69±0.55) and the accumulation pattern of heavy metals from stem of same species was showed in the following pattern Zn (5.15±3.99) > Pb (4.59±3.55) > Cd (3.79±2.93) > Hg (2.51±1.94) > Cr (2.04±1.58) > Cu (1.85±1.43). It was represented in Tables 4 and 5 and Figures 11 and 12. The salt marsh halophyte (*Suaeda monoica*) represents a valuable tool in the restoration of heavy metals from tannery effluent polluted soil[34]. The lead is most toxic heavy metals in the coastal environment. The lead is eliminated from various sources like paints and its industries, dyeing factories, battery manufacturing industries and oil refinery industries etc.

Table 4. Heavy metal concentrations of the plant parts of *Suaeda nudiflora* collected from Ennore Mangrove Ecosystem

Sampling Locations	Suaeda nudiflora plant parts	Heavy metal concentrations (ppm/l for water and ppm/g for sediment)					
		Hg	Cr	Cd	Pb	Cu	Zn
1	Leaf	-	-	-	-	-	-
	Stem	-	-	-	-	-	-
2	Leaf	-	-	-	-	-	-
	Stem	-	-	-	-	-	-
3	Leaf	1.87±0.06[a]	4.31±0.17[a]	5.67±0.38[a]	5.42±0.22[a]	0.95±0.02[a]	4.56±0.05[a]
	Stem	3.77±0.44[a]	3.05±0.57[a]	5.65±0.77[a]	6.87±0.21[a]	2.76±0.17[a]	7.70±0.46[a]
4	Leaf	1.92±0.06[a]	4.45±0.25[a]	5.72±0.41[a]	5.81±0.46[a]	0.98±0.05[a]	4.64±0.08[a]
	Stem	3.85±0.49[a]	3.15±0.20[a]	5.70±0.34[a]	6.91±0.57[a]	2.81±0.59[a]	7.79±0.16[a]
5	Leaf	1.90±0.11[a]	4.33±0.19[a]	5.64±0.36[a]	5.76±0.45[a]	0.94±0.02[a]	4.58±0.10[a]
	Stem	3.72±0.11[a]	3.01±0.09[a]	5.68±0.18[a]	6.89±0.01[a]	2.77±0.01[a]	7.72±0.41[a]
6	Leaf	1.96±0.09[a]	4.35±0.20[a]	5.66±0.38[a]	5.74±0.13[a]	1.29±0.35[a]	4.72±0.12[a]
	Stem	3.76±0.13[a]	3.06±0.10[a]	5.73±0.28[a]	6.90±0.34[a]	2.79±0.34[a]	7.74±0.15[a]

The '–'denotes absence of mangrove plants in selected sampling locations
(The values were average of triplicate samples with standard error and similar alphabets are not significantly different by DMRT (Drunken Multiple Range Test) at 5% level).

Table 5. Heavy metal concentrations of water, sediment and plant parts of mangroves and associated mangrove species collected from Ennore Mangrove Ecosystem

S.No	Sample Name Hg		Heavy metal concentrations (ppm/l for water and ppm/g for sediment)					
			Cr	Cd	Pb	Cu	Zn	
1	Water		7.76±2.84	10.24±2.44	6.82± 1.72	18.12 ± 2.15	2.94±1.21	2.0±0.50
2	Sediment		8.23±1.46	5.44±2.67	5.43±1.96	25.85±14.55	3.49±1.78	2.13±1.27
3	*A. marina*	Leaf	0.89±0.69	1.44±1.11	3.36±2.60	5.19±4.0	0.59±0.46	3.77±2.92
		Stem	3.95±3.06	1.74±1.35	3.6±2.79	5.82±4.55	0.63±0.49	4.36±3.38
		Root	3.69±2.86	5.11±3.96	4.37±3.39	7.26±5.63	0.51±0.39	4.91±3.80
4	*S. portulacastrum*	Leaf	0.31±0.24	1.29±1.00	1.65±1.28	3.98±3.12	0.31±0.24	2.44±1.89
		Stem	0.69±0.53	1.92±1.49	2.70±2.09	4.50±3.48	0.54±0.42	4.41±3.42
		Root	1.27±0.99	2.05±1.59	2.83±2.19	4.68±3.63	0.64±0.50	4.46±3.46
5	*Suaeda nudiflora*	Leaf	1.25±0.98	2.90±2.25	3.78±2.92	3.78±2.93	0.69±0.55	3.08±2.38
		Stem	2.51±1.94	2.04±1.58	3.79±2.93	4.59±3.55	1.85±1.43	5.15±3.99

(The values were average of six sampling locations with standard deviation).

while the growth of marine organisms are affected by antifouling paints, eliminated from bottom side of the boats[11].

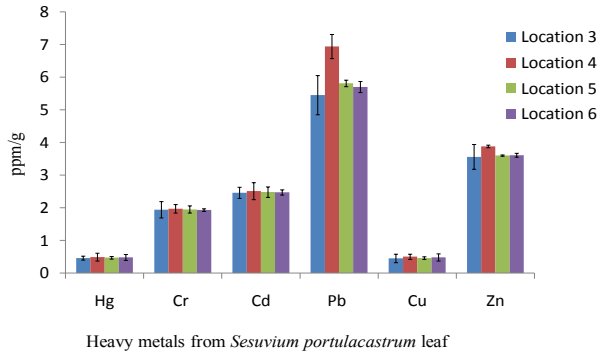

Figure 8. Heavy metal concentration of associated mangroves (*Sesuvium portulacastrum)* plant parts-leaf collected from Ennore Mangrove Ecosystem.

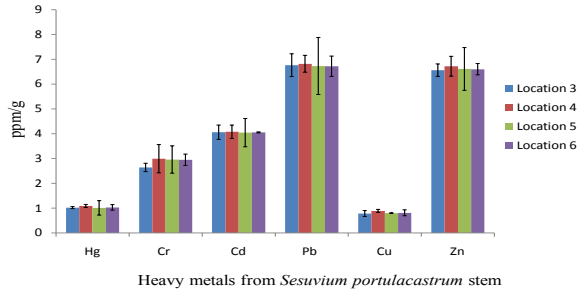

Figure 9. Heavy metal concentration of associated mangroves (*Sesuvium portulacastrum*) plant parts - stem collected from Ennore Mangrove Ecosystem.

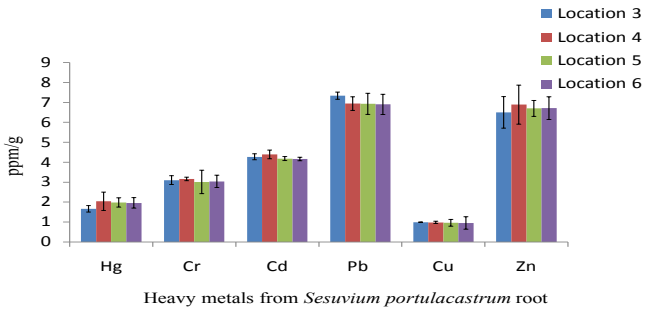

Figure 10. Heavy metal concentrations of associated mangroves (*Sesuvium portulacastrum*) plant parts - root collected from Ennore Mangrove Ecosystem.

The root samples have high concentration of heavy metals accumulation followed by bark and leaves in all the three seasons with the monsoon season showing the maximum concentration for all the metals followed by post-monsoon and pre-monsoon seasons of the estuarine system[23]. Cu and Zn were more concentrated in young leaves than in old leaves[26].

Among the selected metals, high concentration of lead and zinc were accumulated in the mangrove species and associated mangrove species plant parts, water and sediment (Tables 2, 3 and 4 and Figures 11 and 12). Whereas minimum concentration of copper was accumulated in the selected plant parts of mangroves and associated mangroves. The comparison between mangrove plant - *A. marina* and associated mangrove plants - *Sesuvium portulacastrum* and *Suaeda nudiflora* showed that the concentrations of lead, zinc and cadmium were found to be higher in the tissues of A. marina followed by *Sesuvium portulacastrum* and *Suaeda nudiflora* (Tables 2, 3 and 4). The facultative halophyte *Sesuvium portulacastrum* (L.) used as a potential accumulator of Arsenic in polluted sites of coastal region and used to consider a suitable candidate for the phytoremediation of metals[35].

The overall metal concentrations in this studied plant parts of *A. marina*, *Sesuvium portulacastrum* and *Suaeda nudiflora* are provided in Tables 2, 3 and 4 and presented in ppm/g dry weight. It was found that all of the metals concentration in the tissues of the *A. marina*, *Sesuvium portulacastrum* and *Suaeda nudiflora* collected from Ennore Mangrove Ecosystem, the lead (Pb) were significantly varied ($p<0.05$) between selected plants parts or sampling sites. However the following metals ((Hg, Cr, Cd, Cu and Zn) not significantly varied ($p<0.05$) between the plant parts or sampling sites. Among the six metals tested, the lead (Pb) showed higher concentration in mangrove and associated mangrove plant parts followed by zinc (Zn) and chromium (Cr), cadmium (Cd) and mercury (Hg) and copper (Cu). This may be because of availability and accumulation of heavy metals from water and sediments. *A. marina* actively extrudes zinc through the salt secreting process[10]. The results indicated that the Ennore Mangrove Ecosystem has been polluted by heavy metals which finally lead to bioaccumulation of those pollutants in the food chain of the Ennore Mangrove Ecosystem.

Periodical monitoring of the heavy metals in the aquatic system is ensuring continuous safety of communities in the area and also need to practice safe disposal of

domestic wastes and industrial effluents. Strong recommends for recycling the toxic wastes to avoid metals and other contaminants to the environment[36].

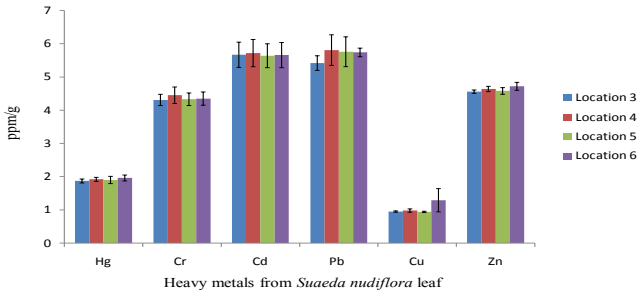

Figure 11. Heavy metal concentrations of the associated mangrove - *Suaeda nudiflora* plant parts – Leaf collected from Ennore Mangrove Ecosystem.

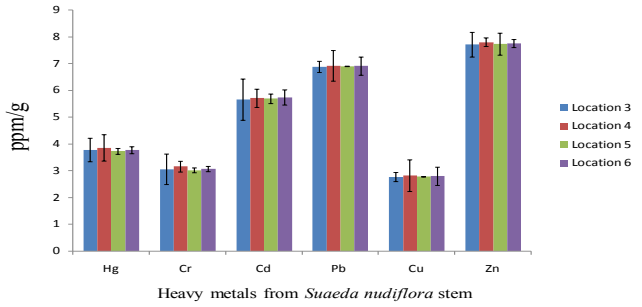

Figure 12. Heavy metal concentrations in associated mangrove *Suaeda nudiflora* plant parts – stem collected from Ennore Mangrove Ecosystem.

4. Conclusion

The findings of this investigation revealed that the Pb, Zn and Cd concentration was high in the following order of *A. marina* > *Sesuvium portulacastrum* > *Suaeda nudiflora*. In over all heavy metals accumulations in the plant tissues, the mangroves species of *Avicenia marina* is better than the associated mangroves species of *Sesuvium portulacastrum* and *Suaeda nudiflora*. Mangrove areas of Ennore creek in north Chennai have been subjected to considerable environmental stress due to the man made activities like urbanization and industrialization, which affected the ecosystem very poorly. In this bad situation, here emerge needs for a potential bioremediator which can take major portion of the toxic elements from the Ennore Mangrove Ecosystem. However the remediation of heavy metals pollution in the coastal environment to reduce their threat to human health and the environmental safety by initiation of environmental friendly approach likes in situ phytoremediation. As a result, the most potent bioaccumulator is *Avicennia marina*, towards the best of its accumulating ability which can be efficiently used as a potent bioremediator or phytostabilizer in the surroundings of the Ennore Mangrove Ecosystem of north Chennai. In addition, we suggest to the state and the central Government for the continuous environmental pollution monitoring to protect Ennore Mangrove Ecosystem.

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