Mangroves- a Potential Phyto-Remediator and Useful Bio-Indicator against Heavy Metal Toxicity

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Article History

Manuscript No. c20
Received in 7th August, 2012
Received in revised form 28th May, 2013
Accepted in final form 3rd June, 2013

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Keywords

Mangroves, heavy metal, phyto-remediation, toxicity, bio-monitor, biochemical indicator

Abstract

Mangroves, the tropical and sub-tropical estuarine eco-system is now under severe threat, of which environmental pollution plays an important role in decreasing the species diversity. The present investigation was undertaken to generate information on the effect of some heavy metals (Hg, Pb, and Cd) on two dominant mangroves of sunderban viz., *Bruguiera sexangula* and *Ceriops decandra.* In both the mangrove species, roots accumulated more heavy metals than stem and leaf linearly correlated with the reduction in growth parameters and the mode of heavy metal accumulation was in the order of Cd>Pb>Hg. Potentiality of *Bruguiera sexangula* and *Ceriops decandra* to grow, establish and thrive within the polluted environment could be effectively used for *phyto-remediation*, however *Bruguiera* was found to be more suited. The visible toxicity symptoms i.e. browning of shoot tip in case of Hg, yellowing of leaves for Pb, chlorosis for Cd etc could be efficiently used as *bio-marker* or *bio-monitor* or *bio-indicator* in the heavy metal polluted environment. Activity assessment of the most important stress enzyme *peroxidase* (POD) clearly indicated that a linear relationship between POD activity and leaf tissue metal concentration was found upto *concentration* 3 (2 times more than the permissible limit) level of all the three heavy metals at 100 DAS for both the mangrove species, but at *concentration* 4 (4 times more than the permissible limit) a sudden decrease in activity was noticed, which is surprisingly associated with the *visible toxicity* symptoms.

1. Introduction

Mangroves, the vast vegetational swamps are the natural transition between land and sea in tropical and subtropical estuarine ecosystem.They play a vital role in proper maintenance of the coastal ecosystem, e.g. they not only protect the shoreline from natural calamities like hurricanes, tsunami etc. but also are the only escape from environmental pollution of the nearby industrial growth. Mangroves also have significant local economic importance as source of timber, firewood, pulp, honey, tannin, wax and also for natural and manipulated fisheries etc., but this economic and ecological utility of mangrove community is now under severe threat mainly due to demographic pressure, rapid urbanization, industrialization and human interference and random exploitation. While about 500,000 ha of mangrove forest existed in India during the 60's, such area was brought down to 200,000 ha only during the 80's (Blasco, 1977). Similar observation was also reported by Untawale (1986). The causes of such depletion and degeneration are of course numerous, of which environmental pollution including heavy metals [like mercury (Hg), lead (Pb), cadmium (Cd), etc.] play an important role. Moreover, these inorganic contaminants (heavy metals) are getting importance for their non-degradable nature and they often accumulate through tropic level causing a deleterious biological effect. Stiborova et al. (1987) reported shoot and root growth retardation of barley and maize after heavy metal exposure. Similar findings were also observed by Iqbal et al. (1991), Krupa et al. (1993) and Zeid (2001).

In the present experiment it was proposed to generate information on the effect of some identified heavy metals (Hg, Pb and Cd), commonly found in the estuarine eco-system, on two dominant mangroves of Sunderban viz., *Bruguiera sexangula* and *Ceriopas decandra,* regarding their different morphological, physiological and biochemical characters at two growth stages in *ex-situ* condition. The result obtained from this type of study will help us for better understanding of the effect of heavy metals on two dominant mangroves of Sunderban and also help to identify the species which could be used as *Biomarker* or *Biomonitor* to heavy metal pollution as well as to generate information on phyto-remediation properties of mangroves, if any; thus help to select the potential mangrove species which can grow, establish and thrive within polluted environment.

2. Materials and Methods

Two mangrove species *Bruguiera sexangula* and *Ceriops decandra* were collected from Patharpratima area for the present research work, as they were found to be the most dominant and commonly available species in the Sunderban area. The area of research, i.e. the Patharpratima area of Sunderban, was correctly selected as it was very close to the discharge point of river Hooghly. The concentrations of different heavy metals like Hg, Pb, and Cd in Patharpratima were estimated as 0.573, 40.40 and 25.79 µg g^{-1} in soil and in water their concentrations were 3.35, 242.50 and 40.50 µg l^{-1}, respectively. The concentrations of all these heavy metals exceeded permissible limit for crop production (BIS, 1991).

The mature plant propagules of the said mangroves were planted in earthen pots. The sands of the earthen pots were sterilized with 5% Formalin. 30 plants in three replications were planted in the net house of the Department of Seed Sciences and Technology, Bidhan Chandra Krishi Viswavidyalaya, West Bengal. The plants were treated with four different concentrations of three heavy metals viz. Hg, Pb and Cd. Out of four concentrations; one concentration (conc. 2) was prepared as per the permissible limit of heavy metals in drinking water, one concentration was maintained at lower level of the permissible limit (conc. 1) and two other concentrations (conc. 3 & 4) were above that as follows :

Heavy metals	Conc.-1 (mg l^{-1})	Conc.-2 (mg l^{-1})	Conc.-3 (mg l^{-1})	Conc.-4 (mg l^{-1})
Hg	0.005	0.01	0.02	0.04
Pb	1.0	2.0	4.0	8.0
Cd	1.0	2.0	4.0	8.0

(Source**:** West Bengal Pollution Control Board website-www.wbpcb.gov.in)

All the treatments were prepared in distilled water and supplemented with modified Hoagland nutrient solution (Hoagland and Arnon, 1938) at 7 days interval. The control plants were provided with only standard Hoagland nutrient solution. Different plant parts like root, stem and leaves were collected at two different growth stages namely 50 Days after sowing (DAS) and 100 DAS for assessing heavy metal accumulation in each plant part. This was estimated by wet oxidation method with Di-acid mixture without H_2SO_4 (Jackson, 1973) and the reading was recorded from Varian-AA240 Atomic Absorption Spectrometer. Morphological data and other visible features were recorded at both the growth stages and the average values from 3 replications. For assessing the activity of stress enzyme peroxidase, leaf samples were collected at both the growth stages and the activity was estimated as per the standard method of Malik and Singh (1980). Statistical analysis was done by augmented two factor factorial ANOVA using Duncan's test (Duncan, 1955).

3. Results and Discussion

The results obtained from Atomic Absorption Spectrophotometry indicated that in case of *Ceriops decandra*, root accumulates more (0.83 µg g^{-1}) amount of Hg at concentration 4 at 50 DAS than its stem and leaf (Table 1). Similarly in *Bruguiera sexangula,* root accumulated much higher (0.94 µg g^{-1}) amount of Hg at concentration 4 after 50 DAS. The trend of more heavy metal accumulation in root area was also noticed at 100 DAS for both the species, which might be due to less mobility of toxic heavy metals within the plant body. Sur et al. (2006) reported such type of less mobility of heavy metals at higher concentrations, in the edible portion of different vegetables. Similar finding was reported earlier by Tam et al. (1997) and Wei et al. (2008). This clearly indicates that roots act as a barrier for heavy metal translocation and protects the sensitive parts of the plant.

The mode of heavy metal accumulation in both *Bruguiera* and *Ceriops* was in the order of Cd>Pb>Hg (Table 1). Lin et al. (1997) and Lian et al. (1999) observed similar trend of heavy metal absorption in mangrove species. Hameed et al. (2001) reported that Pb accumulation is much faster and greater than Cu in the leaves of *Spinancea oleracea*. Ramos and Geraldo (2007) showed that bioaccumulation of heavy metals in three mangrove species like *Avicennia schaueriana*, *Laguncularia recemosa* and *Rhizophora mangle* were in the order of Zn>Pb>Cr>Cu>Cd and concluded that those plants could be efficiently used as biological indicator of heavy metal pollution. It was also observed that there was an increased tendency of hyper-accumulation of heavy metals with increased concentrations and time for both the mangrove species and *Bruguiera* accumulates more amount of heavy metals than *Ceriops*; e.g. in *Bruguiera*, at highest concentration, root accumulated 1.28 µg g^{-1} Hg, 11.0 µg g^{-1} Pb and 35.12 µg g^{-1} Cd after 100 days of growth in pot culture which was much higher than that of *Ceriops* (Table 1). Similarly, sunflowers and *Sesbania drummondii* were identified as hyper-accumulator of uranium and lead, respectively, by Dushenkov et al. (1995) and Barlow et al. (2000).

The morphological study when compared between control and treated plants, it was interestingly found that there was a drastic reduction in plant height, fresh and dry weight of shoot and root particularly in *Ceriops decandra* than *Bruguiera sexangula*

Table 1: Assessment of heavy metal accumulations (μg g^{-1}) in different plant parts of two mangrove species at different growth stages

Treatments	*Bruguiera* sp.						*Ceriops* sp.					
	50 DAS			100 DAS			50 DAS			100 DAS		
	Root	Stem	Leaf	Root	Stem	Leaf	Root	Stem	Leaf	Root	Stem	Leaf
Hg 1	BDLk	BDLk	BDLi	0.41^{i}	0.24^{j}	0.22^{j}	BDLk	BDLj	BDLk	BDLl	BDLl	BDLl
Hg 2	0.61^{f}	0.20^{i}	0.16^{g}	0.63^{h}	0.31^{i}	0.28^{i}	0.21^{i}	0.11^{i}	0.08^{j}	0.34^{k}	0.16^{k}	0.09^{k}
Hg 3	0.81^{e}	0.38^{g}	0.22^{f}	0.91^{g}	0.45^{h}	0.32^{h}	0.64^{g}	0.21^{f}	0.14^{i}	0.81^{j}	0.34^{j}	0.18^{j}
Hg 4	0.94^{d}	0.62^{d}	0.34^{e}	1.28^{f}	0.76^{g}	0.53^{g}	0.83^{e}	0.54^{h}	0.28^{g}	1.18^{h}	1.11^{g}	0.72^{h}
Control	BDLk	BDLk	BDLi	BDLl	BDLl	BDLl	BDLk	BDLj	BDLk	BDLm	BDLl	BDLl
Pb 1	BDLk	BDLk	BDLi	2.22^{e}	1.76^{e}	1.10^{e}	0.12^{j}	BDLj	BDLk	1.91^{f}	1.39^{f}	0.81^{f}
Pb 2	1.06^{c}	0.94^{c}	0.36^{d}	3.42^{d}	2.14^{d}	1.26^{d}	0.61^{h}	0.31^{g}	0.22^{h}	2.42^{e}	1.64^{e}	0.86^{e}
Pb 3	1.26^{b}	1.11^{b}	0.98^{b}	6.14^{c}	3.21^{c}	2.09^{c}	0.76^{f}	0.61^{e}	0.34^{f}	3.44^{d}	1.98^{d}	0.96^{d}
Pb 4	3.75^{a}	1.22^{a}	1.15^{a}	11.02^{b}	8.75^{b}	6.43^{b}	1.46^{c}	0.72^{d}	0.70^{c}	9.94^{b}	2.01^{c}	1.26^{c}
Control	BDLk	BDLk	BDLi	BDLl	BDLl	BDLl	BDLk	BDLj	BDLk	BDLm	BDLl	BDLl
Cd 1	0.11^{j}	BDLk	BDLi	0.28k	0.16^{k}	0.12^{k}	0.63^{g}	0.60^{e}	0.51^{e}	0.96^{i}	0.79^{i}	0.58^{i}
Cd 2	0.15^{i}	0.12^{j}	0.08^{h}	0.32^{j}	0.18^{k}	0.15^{k}	1.24^{d}	0.85^{c}	0.62^{d}	1.65^{g}	0.96^{h}	0.74^{g}
Cd 3	0.34^{h}	0.22^{h}	0.16^{g}	1.28^{f}	1.10^{f}	0.96^{f}	4.38^{b}	2.22^{b}	1.16^{b}	8.74^{c}	2.34^{b}	1.98^{b}
Cd 4	0.50^{g}	0.42^{f}	0.40^{c}	35.12^{a}	31.41^{a}	22.63^{a}	9.38^{a}	3.42^{a}	2.91^{a}	17.88^{a}	4.03^{a}	3.01^{a}
Control	0.001^{k}	BDLk	BDLi	0.0021	BDLl	BDLl	BDLk	BDLj	BDLk	0.001m	BDLl	BDLl

Note : BDL ≡ Below Detectable Limit. Similar alphabets denote homogeneous means due to DMRT at 5% level of significance

(Table 2 and 3). These findings of decreased plant height with increased concentrations of heavy metals and time was at par with the findings of Stiborova et al. (1987), Iqbal et al. (1991), Mac Farlane and Burchett (2002), Adhikary et al. (2004), Mahmood et al. (2007) and Rahman et al. (2009) and the reduction in plant height, fresh and dry weight of shoot and root was found to be linearly correlated with increased concentrations of heavy metals and days after plantation. As these growth parameters are the indicator of plant vigour, so it clearly concludes that accumulation of heavy metals in different plant parts of *Ceriops* and *Bruguiera* disrupted plant metabolism.

From the above findings, it could be clearly stated that though retarded plant growth along with decreased fresh and dry weight of root and shoot was observed for heavy metal treatments in both the mangrove species (Table 2 and 3), but they did not interfere with the completion of plant development and survived even under a considerable pollution load. Such observation was supported by earlier findings of Kholodova et al. (2005). This clearly indicates the potentiality of *Bruguiera sexangula* and *Ceriops decandra* in general and the *Bruguiera sexangula* in specific to grow, establish and thrive within the polluted environment. Thus they could be efficiently used as phyto-remediator of these heavy metals. The genus *Bruguiera* was identified as the hyper-accumulator of these three heavy metals and is more suited for plantation programme in a polluted area for its sustainable management. Zhou et al. (2011) reported that mangrove plants can absorb and store non-essential metals in their perennial tissues and thus reduce export of the metals via leaf litter transport and also proposed that the mangroves are excellent candidates for phyto-stabilization of heavy metals in inter-tidal substrates.

Moreover, it was quite interestingly found that some sorts of visible toxicity symptoms were observed at only 100 DAS growth stage in both the mangrove species viz., browning of shoot tip in case of Hg, yellowing of leaves for Pb, chlorosis for Cd etc. (Table 4). But these anomalies were observed only in case of the highest concentrations of each heavy metal treatments. Hence, these two mangrove species could be efficiently used as Bio-marker or Bio-monitor in the heavy metal polluted environment. Rahman et al. (2009) also reported similar kind of toxicity symptoms like chlorosis, necrosis and finally death of the plant due to the effect of high concentration of Cr and explained it as their interference to several metabolic processes. Sharma (2001) reported different pollution indicator plants like *Anthoxanthum* for Zn, *Agrostis* for Cu, *Festuca* for Pb and *Impatiens* for Cd. A similar finding was also reported by Mac Farlane and Burchett (2001) and Rappe et al. (2011).

The activity measurement of stress enzyme, peroxidase (POD) indicated more value in control plants at 50 DAS than at 100 DAS (Table 5) for both *Bruguiera* and *Ceriops* sp. A linear relationship between peroxidase activity and leaf tissue metal concentration was observed for all the three heavy metals upto

Table 2: Average growth parameters of *Bruguiera* sp. at 50 days and 100 days after sowing (DAS)

Treat-ments	50 DAS					100 DAS				
	Plant height (cm)	Root fresh weight (g)	Root dry weight (g)	Shoot fresh weight (g)	Shoot dry weight (g)	Plant height (cm)	Root fresh weight (g)	Root dry weight (g)	Shoot fresh weight (g)	Shoot dry weight (g)
Control	21.65^{a}	1.01^{a}	0.27^{b}	1.65^{a}	0.41^{a}	33.00^{a}	1.65^{a}	0.55^{a}	1.78^{c}	0.49^{b}
Hg 1	16.75^{d}	0.88^{e}	0.22^{f}	0.98^{g}	0.36^{c}	19.52^{e}	1.29^{c}	0.54^{a}	1.29^{e}	0.41^{e}
Hg 2	13.21^{g}	0.93^{c}	0.25^{d}	1.39^{c}	0.39^{b}	15.83^{f}	1.42^{b}	0.51^{b}	1.44^{d}	0.44^{d}
Hg 3	12.06^{h}	0.97^{b}	0.26^{c}	1.04^{f}	0.22^{g}	14.05^{i}	1.45^{b}	0.47^{c}	1.05^{f}	0.26^{i}
Hg 4	9.58^{i}	0.78^{f}	0.21^{g}	0.41^{m}	0.11^{j}	10.60^{j}	0.85^{g}	0.3^{f}	0.55^{k}	0.16l
Pb 1	20.81^{b}	0.90^{d}	0.32^{a}	1.52^{b}	0.32^{d}	23.70^{b}	1.17^{d}	0.45^{cd}	2.16^{a}	0.51^{a}
Pb 2	18.50^{c}	0.77^{f}	0.21^{g}	1.13^{e}	0.28^{e}	22.57^{c}	1.05^{e}	0.44^{d}	1.98^{b}	0.47^{c}
Pb 3	16.92^{d}	0.63^{h}	0.17^{h}	0.92^{h}	0.20^{h}	15.23^{gh}	0.83^{gh}	0.33^{f}	0.78^{i}	0.28^{h}
Pb 4	14.28^{f}	0.61^{i}	0.17^{h}	0.58^{l}	0.17^{i}	14.97^{h}	0.81^{h}	0.31^{f}	0.63^{j}	0.20^{j}
Cd 1	15.70^{e}	0.95^{c}	0.25^{d}	1.19^{d}	0.29^{e}	20.14^{d}	1.27^{c}	0.45^{cd}	1.28^{e}	0.35^{f}
Cd 2	12.34^{h}	0.93^{c}	0.23^{e}	0.85^{i}	0.26^{f}	15.33^{g}	1.01^{f}	0.37^{e}	0.99^{g}	0.30^{g}
Cd 3	9.15^{i}	0.62^{i}	0.21^{g}	0.81^{j}	0.21^{gh}	10.50^{j}	0.66^{j}	0.25^{g}	0.89^{h}	0.25^{i}
Cd 4	7.43^{j}	0.69^{g}	0.22^{fg}	0.65^{k}	0.11^{j}	8.73^{k}	0.72^{i}	0.27^{g}	0.34l	0.19^{k}

Note : Similar alphabets denote homogeneous means due to DMRT at 5 % level of significance.

Table 3: Average growth parameters of *Ceriops* sp. at 50 days and 100 days after sowing (DAS)

Treat-ments	50 DAS					100 DAS				
	Plant height (cm)	Root fresh weight (g)	Root dry weight (g)	Shoot fresh weight (g)	Shoot dry weight (g)	Plant height (cm)	Root fresh weight (g)	Root dry weight (g)	Shoot fresh weight (g)	Shoot dry weight (g)
Control	5.09^{b}	0.25^{a}	0.06^{b}	0.08^{b}	0.025^{a}	7.60^{a}	0.29^{a}	0.10^{a}	0.56^{a}	0.098^{a}
Hg 1	4.76^{d}	0.15^{d}	0.05^{d}	0.07^{cd}	0.019^{c}	6.00^{c}	0.19^{e}	0.05^{e}	0.28^{e}	0.061^{h}
Hg 2	4.23^{f}	0.14^{e}	0.04^{f}	0.05^{f}	0.011^{fg}	5.67^{de}	0.17^{f}	0.04^{g}	0.21^{f}	0.055^{i}
Hg 3	3.90^{h}	0.07^{i}	0.02^{h}	0.04^{h}	0.008^{h}	4.23^{j}	0.10^{j}	0.03^{j}	0.15^{g}	0.031^{k}
Hg 4	1.90^{j}	0.06^{j}	0.01^{i}	0.02^{i}	0.006^{i}	2.40l	0.08^{k}	0.02^{k}	0.10^{h}	0.026l
Pb 1	4.86^{c}	0.18^{c}	0.05^{c}	0.07^{c}	0.023^{b}	5.83^{cd}	0.20^{d}	0.07^{b}	0.39^{b}	0.093^{b}
Pb 2	4.28^{ef}	0.14^{f}	0.04^{e}	0.06^{e}	0.013^{e}	5.30^{f}	0.17^{f}	0.06^{c}	0.33^{d}	0.082^{c}
Pb 3	4.14^{g}	0.13^{g}	0.04^{f}	0.05^{g}	0.010^{gh}	4.50^{i}	0.15^{h}	0.05^{d}	0.15^{g}	0.038^{j}
Pb 4	3.10^{i}	0.03^{k}	0.01^{j}	0.02^{i}	0.002^{j}	3.77^{k}	0.10^{j}	0.02l	0.06^{i}	0.019^{m}
Cd 1	5.62^{a}	0.22^{b}	0.08^{a}	0.11^{a}	0.023^{b}	6.27^{b}	0.27^{b}	0.10^{a}	0.39^{b}	0.080^{d}
Cd 2	4.87^{c}	0.18^{c}	0.04^{f}	0.07^{c}	0.015^{d}	5.63^{e}	0.22^{c}	0.04^{f}	0.37^{c}	0.076^{e}
Cd 3	4.33^{e}	0.13^{g}	0.03^{g}	0.07^{d}	0.012^{ef}	5.10^{g}	0.15^{g}	0.04^{h}	0.36^{c}	0.073^{f}
Cd 4	4.14^{g}	0.09^{h}	0.03^{g}	0.04^{h}	0.011^{fg}	4.77^{h}	0.13^{i}	0.04^{i}	0.20^{f}	0.070^{g}

Note: Similar alphabets denote homogeneous means due to DMRT at 5% level of significance.

Concentration 3 (2 times more than the permissible limit) level at 100 DAS for both the species. In *Ceriops*, while the activity was 0.016 unit min^{-1} mg^{-1} in control at 100 DAS, but it was increased from 0.019 to 0.024 from Hg 1 to Hg 3 and then drastically reduced to 0.013 unit min^{-1} mg^{-1} in Hg 4 treatment. Moreover, this decrease in peroxidase activity at the Concentration 4 (4 times more than the permissible limit) of all the three heavy metals at 100 DAS was also associated with visible toxicity symptoms in both the mangrove species. This may be due to the fact that the treatment 4 of all the three heavy metals was with just the double amount of chemicals than in concentration 3. This result corroborates the findings of Mac Farlane and Burchett (2001) and Shevyakova et al. (2003). Zhang et al. (2007) also studied the effect of heavy metal stress on activity of antioxidative enzyme peroxidase in leaves and roots of two mangrove plants and observed that though the

Table 4: List of visible toxicity of mangroves due to heavy metal treatments at 100 DAS

Treatment	Visible toxicity symptoms	
	Bruguiera sp.	*Ceriops* sp.
Hg 4	Browning of shoot tip Stunted Growth	Stunted growth
Pb 4	Yellowing of leaves Broom like shoot tip Chlorosis	Yellowing of leaves Stunted growth Chlorosis
Cd 4	stunted growth	Bronzing of leaves

Table 5: Assessment of average peroxidase activity (unit min^{-1} mg^{-1}) of two mangrove species

Treatments	*Bruguiera* sp.		*Ceriops* sp.	
	50 DAS	100 DAS	50 DAS	100 DAS
Control	0.053^{k}	0.011^{e}	0.038^{j}	0.016^{h}
Hg 1	0.055^{j}	0.018^{b}	0.072^{e}	0.019^{g}
Hg 2	0.058^{i}	0.019^{b}	0.074^{d}	0.022^{f}
Hg 3	0.062^{h}	0.021^{a}	0.077^{c}	0.024^{e}
Hg 4	0.065^{g}	0.008^{f}	0.078^{c}	0.013^{i}
Pb 1	0.157^{c}	$0.012d^{e}$	0.074^{d}	0.017^{h}
Pb 2	0.162^{b}	0.016^{c}	0.077^{c}	0.019^{g}
Pb 3	0.165^{a}	0.019^{b}	0.081^{b}	0.022^{f}
Pb 4	0.166^{a}	0.007^{f}	0.083^{a}	0.013^{i}
Cd 1	0.088^{f}	0.011^{e}	0.052^{i}	0.035^{c}
Cd 2	0.092^{e}	0.013^{d}	0.054^{h}	0.042^{b}
Cd 3	0.094^{e}	0.016^{c}	0.055^{g}	0.048^{a}
Cd 4	0.097^{d}	0.007^{f}	0.058^{f}	0.027^{d}

POD activity was increased first but finally declined and they concluded that POD activity may be served as a biomarker to heavy metal stress.

4. Conclusion

Peroxidase activity can be efficiently used as a sensitive biochemical indicator of Cd, Pb and Hg stress in *Bruguiera* and *Ceriops species*

4. References

Adhikari, T., Manna, M.C., Singh, M.V., Wanjani, R.H., 2004. Bioremediation measure to minimize heavy metals accumulation in soils and crops irrigated with city effluent. Journal of Food Agriculture and Environment 2, 266-270.

Barlow, R., Bryan, N., Andersland, J., Sahi, S., 2000. Lead hyper accumulation by *Sesbania drummondii*. In: Proceedings of Conference on Hazardous Waste Research, 112-114.

BIS., 1991. Indian standards drinking water specification, Bereau of Indian Standards, Indian Standard 10500.

Blasco, F., 1977. Outlines of Ecology, Botany and Forestry of the Mangals of the Indian Subcontinent, West Coastal Ecosystems. Elsevier Scientific Publishing Company, Oxford, New York. 241-258.

Duncan, D.B., 1955. Multiple range and multiple F tests. Biometrics 11, 11-42.

Dushenkov, V., Nanda Kumar, P.B.A., Motto, H., Raskin, I., 1995. Rhizofiltration : The use of plants to remove heavy metals from aqueous streams. Environmental Science and Technology 29, 1239-1245.

Hameed, N.Z., Siddiqui, S., Ahmed, S., 2001. Effect of Cu and Pb on germination, accumulation and phenolic contents of *Spinancea oleraecea* and *Lycopersicum esculentum*. Pakistan Journal of Biological Sciences 4, 809-811.

Hoagland, D.R., Arnon, D.I., 1938. The water-culture method for growing plants without soil. California Agricilture Experimental Station Circular, 347.

Iqbal, M.Z., Mahmood, M.T., Ahmed, F., 1991. Influence of cadmium toxicity on germination and growth of some common trees. Pakistan Journal of Scientific and Industrial Research 34, 140-142.

Jackson, M.L., 1973. Soil chemical analysis. Prentice Hall of India Private Ltd. New Delhi.

Kholodova, V.P., Volkov, K.S., Kuznetsov, V.V., 2005. Adaptation of the common ice plant to high copper and zinc concentrations and their potential using for phytoremediation. Russian Journal of Plant Physiology 52(6), 748-757.

Krupa, Z., Gunnar, O., Humer, N.P.A., 1993. The effects of cadmium on photosysthesis of *Phaseolus vulgaris*: a fluorescence analysis. Physiololy of Plants 38, 626-630.

Lian, Y.W., Xu, J., Lin, P., Meguro, S., Kawachi, S., 1999. Five heavy metals in propagules of ten mangrove species of China. Journal of Wood Sciences 45(4), 343-347.

Lin, P., Zheng, W., Li, Z.J., 1997. Distribution and accumulation of heavy metals in *Avicennia marina* community in Shenzhen, China. Journal of Environmental Sciences 9(4), 472-479.

MacFarlane, G.R., Burchett, M.D., 2001. Photosynthetic pigments and peroxidase activity as indicators of heavy metal stress in the grey mangrove, *Avicennia marina* (Forsk.) Vierh. Marine Pollution Bulletin 42(3), 233-240.

MacFarlane, G.R., Burchett, M.D., 2002. Toxicity, growth and accumulation relationships of copper, lead and zinc in the grey mangrove *Avicennia marine* (Forsk.) Vierh. Marine Environmental Research 54(1), 65-84.

Mahmood, T., Islam, K.R., Muhammad, S., 2007. Toxic effects of heavy metals on early growth and tolerance of cereal crops. Pakistan Journal of Botany 39(2), 451-462.

Malik, C.P., Singh, M.B., 1980. Plant enzymology and Histoenzymology. Kalyani Publishers, New Delhi. 53.

Rahman, M.M., Chonling, Y., Rahman, M.M., Islam, K.S., 2009. Accumulation, distribution and toxicological effects induced by chromium on the development of mangrove plant *Kandelia candel* (L.) Druce. Revista ambiente & Agua 4(1), 6-19.

Ramos, G.M., Geraldo, L.P., 2007. Assessment of *Avicennia schaueriana*, *Laguncularia recemosa* and *Rhizophora mangle* plant species as bioindicator of heavy metal pollution in mangrove environments. Engenharia-Sanitaria-e -Ambiental 12(4), 440-445.

Rappe, R.A., Lajus, D.L., Schreider, M.J., 2011. Heavy metal impact on growth and leaf asymmetry of seagrass, *Halophila ovalis*. Journal of Environmental Chemistry and Ecotoxicology 3(6), 149-159.

Sharma, P.D., 2001. Ecology and Environment. Rastogi Publications, Meerut, India, 517-530.

Shevyakova, N.I., Netronina, I.A., Arnova, E.E., Kuznetsov, V.V., 2003. Compartmentation of cadmium and iron in *Mesembryanthemum crystallinum* plants during the adaptation to cadmium stress. Russian Journal of Plant Physiology 50(5), 678-685.

Stiborova, M., Ditrichova, M., Brezinova, A., 1987. Effect of heavy metal ions on growth and biochemical characteristics of photosynthesis of barley and maize seedlings. Biology of Plants 29, 453-467.

Sur, P., Pandit, T.K., Naik, S.K., Mandal, M., Chakrabarty, A., Das, D.K., 2006. Occurrence of some heavy metals in some contaminated soils and crops of West Bengal. Indian Agriculture 50(1-2),79-84.

Tam, N.F.Y., Wong, Y., Wong, Y.S., 1997. Accumulation and distribution of heavy metals in a stimulated mangrove system treated with sewage. Asia-pacific conference on science and management of coastal environment. In: Proceedings of the International Conference, Hong Kong, 25-28 June 1996. Hydrobologia 352, 67-75.

Untawale, A.G., 1986. Mangrove Ecosystem in India. In: Mangroves of Asia and Pacific : Status and Management. UNESCO, 51-87.

Wei, L., Yan, C.L., Wu, G.R., Guo, X.Y., Ye, B.B., 2008. Variation of delta 13C in *Aegiceras corniculatum* seedling induced by cadmium application. Ecotoxicology 17(6), 480-484.

Zeid, I.M., 2001. Responses of *Phaseolus vulgaris* to chromium and cobalt treatments. Biologia Plantarum 44(1), 11-115.

Zhang, F.Q., Wang, Y.S., Lou, Z.P., Dong J.D., 2007. Effect of heavy metal stress on antioxidative enzyme and lipid peroxidation in leaves and roots of two mangrove plant seedlings (*Kandelia candel* and *Bruguiera gymnorrhiza*). Chemosphere 67(1), 44-50.

Zhou, Y.W., Peng, Y.S., Li, X.L., Chen, G.Z., 2011. Accumulation and partitioning of heavy metals in mangrove rhizosphere sediments. Environmental Earth Science 64(3), 799-807.