Role of ecosystem components in Cd removal process of aquatic ecosystem

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Abstract

Experiment was conducted using fifteen glass aquariums to ascertain the pathways of removal of cadmium through numerical and compositional manipulation of ecosystem components and their role in Cd removal in different aquatic ecosystem. Each aquarium was provided with surface sediment @ 2 kg, filled with 15 L tap water and randomly distributed into five treatments having three replicates in each. Cadmium chloride (CdCl_2) of analytical grade was added @ 2 mg/L to the water of each aquarium and mixed gently. Except first one, rest four systems received unio (*Lamellidens marginalis*, 55 ± 2.5 g) @ 6 pieces/aquarium. Tilapia (*Oreochromis mossambicus*, 35 ± 3 g) was introduced @ 6 fish/aquarium in third and fifth system, where as pistia (*Pistia stratiotes*) was introduced @ 50 g/aquarium in fourth and fifth system for 28 days observation period. The samples of water, sediment, unio, fish and pistia were collected from different system at every seven days intervals and analyzed. Results revealed that mean substantial reduction of Cd in water varied between 1.820 to 1.994 mg/L in

different simulated ecosystem. Ecosystem efficiency of Cd removal was varied in different ecosystems and showed highest (11%) value in the ecosystem carrying five components that suggested a cumulative effect of increasing number of components employed in different simulated aquatic ecosystem significantly facilitated to reduce the level of Cd concentration in water column. Pistia exerted (10 – 204 times) higher rate of Cd accumulation over the other components employed in five simulated ecosystems of various component structures. Therefore, in the present study, it may be concluded that ecosystem carrying five components exhibited best performance for optimum minimization of Cd removal from water column. It can also be concluded that ecosystem components showed a variable performance and pistia was the efficient component in Cd removal point of view.

Key words: Cadmium, ecosystem, ecosystem component, cadmium removal efficiency.

1. Introduction

Cadmium is a ‘priority pollutant’, not only from the human health perspective, but also from a broader ecosystem viewpoint (Campbell, 2006). In general, it is a biologically non-essential, non-biodegradable, persistent type of heavy metal and its compounds are known to have high toxic potentials. There is increasing concern regarding the likely impact of cadmium in the environment, because it is a carcinogenic element posing risks to ecosystems and humans, and is hazardous in excessive amounts (SCOPE, 2000). Another important adverse property of cadmium is their ability of amply accumulating in the sediments and in the aquatic flora and fauna (by bioaccumulation and biomagnification) that causing a gross biological impact.

Industrial effluents and agricultural runoff containing toxic and hazardous substances including heavy metals discharge into water and tremendously contaminate the aquatic

environment (Munger et al., 1999, Gbem et al., 2001 and Woodling et al., 2001). Cadmium emissions to water arise, in decreasing order of importance, from phosphate fertilizers, non-ferrous metals production, and the iron and steel industry (OECD, 1994, ERL, 1990 and Van Assche and Ciarletta, 1992).

Sediments absorb heavy metals such as lead, zinc, copper, nickel, cadmium, chromium etc. from water and accumulate in its different tiers. The view is emerging in certain quarters that cadmium from phosphorus fertilizers poses a potentially serious threat to soil quality and, through the food chain, to human health (Oosterhuis et al., 2000).

Aquatic organisms take up heavy metals, concentrate them to amounts considerably higher than those found in the environment (Ferard et al., 1983) and exhibit toxicity effects (Witeska et al., 1995 and Pelgrom et al., 1994). Benthic communities take up heavy metals from environment and are generally characterized by reduced abundance, lower species diversity, and shifts in community composition from sensitive to tolerant taxa (Winner et al., 1980, La Point et al., 1984 and Clements, 1991). Jana and Das (1997) put forwarded that *Lamellidens* might be used as a biofilter for the reclamation of cadmium contaminated aquatic environment. Cadmium is also an important xenobiotic and cumulative pollutant in aquatic ecosystems and fish are particularly vulnerable to cadmium exposure (Sorensen, 1991). In fish, cadmium uptake is took place mainly through three routes namely, gills, skin and also from food via the intestinal wall and accumulated (Karlsson-Norrgran and Runn, 1985; Edgren and Notter, 1989 and Kumada et al., 1980). On the other hand, the metal retention capacity of fish is dependent on the metal assimilation and excretion capacities of the fish concerned (Rao and Patnaik, 1999). Aquatic plants uptake the substances from contaminated aquatic environment via surface of the roots and leaves (i.e., phytoremediation), which helps in cleaning up heavy metals, pesticides and

xenobiotics (Suresh and Ravishankar, 2004), organic compounds (Newman and Reynolds, 2004), toxic aromatic pollutants (Singh and Jain, 2003) and acid mine drainage (Archer and Caldwell, 2004).

Cadmium uptake by these above discussed ecosystem components is a significant aspect in ecosystem based reclamation of aquatic environment which is presently being eco-friendly recognized approach. Understanding of the efficiency of different ecosystem based managed models of various numerical and compositional structure of components to remove heavy metal from the aqueous phase is important in the present hazardous heavy metal polluted aquatic environment. There is scanty of information regarding the role of different ecosystem components under various ecosystems to minimize the heavy metal toxicants in aqueous medium. Development of such promising ecosystem model depending on various numerical and compositional structures of components would play a significant role to provide a heavy metal like toxic elementless aquatic environment. Therefore, the present study has been focused to ascertain the pathways of removal of cadmium through numerical and compositional manipulation of ecosystem components and their role in Cd removal in different aquatic ecosystem.

2. Materials and Methods

Study used fifteen glass aquariums (20 L), were provided with surface sediment (Silt 20%, mud/clay 75%, sand 5% and pH 7.4) at the bottom which was collected from four different sites of a local pond using a suitable hand grab sampler, mixed to create homogenous one, dispensed at the rate of 2 kg/aquarium and filled with 15 L tap water (pH 7.6 and temperature 28.5). All the aquariums were randomly distributed into five treatments of three replicates (each treatment

herein called as ecosystem i.e, ES₁ – ES₅). Cadmium chloride [CdCl₂, E. Merck (India) Ltd.] of analytical grade was collected from market and added @ 2mg/L to water of each aquarium and mixed gently.

Unio (*Lamellidens marginalis*, 55 ± 2.5 g), tilapia (*Oreochromis mossambicus*, 35 ± 3 g) and pistia (*Pistia stratiotes*) were procured from a local fish pond, acclimatized for a week and employed as benthic organism, water column habitant and aquatic plant in simulated experimental system, respectively. Except ES₁, rest four systems received unio @ 6 pieces/aquarium and tilapia introduced @ 6 fish/aquarium in ES₃ and ES₅ where as pistia introduced @ 50 g/aquarium in ES₄ and ES₅ for 28 days observation period. Loss of water due to sampling was compensated by adding the equal volume of same water. Designed five simulated ecosystems have been shown in figure 1.

The samples of water (100 mL), sediment (25 gm), unio (one), fish (one) and pistia (8 gm) were collected from different aquarium at a fixed hour (9.00 am) at every seven days intervals using a suitable small hand made specific samplers for different types of samples. Water and sediment samples were collected from four sites of each aquarium and then pooled into one for each aquarium before final analysis. For analysis of the cadmium (Cd) 100 mL water samples were digested with 2 mL nitric acid in Kjeldahl flask. Sediment and whole organisms of unio, fish and plant samples of each aquarium were dried overnight at 100°C, make a fine powder and sieved the powder of whole organism through a 63 µm mesh to get equal size of particles smaller than 63 µm (Fenchel et al., 1975) for easy digestion. Twenty mL of concentrated nitric acid was added to 1 g of each of the dried powder samples in Kjeldahl flask and were digested within a digestion chamber at 80°C (Bat and Raffaelli, 1999). After digestion the resultant solutions were allowed to cool and the residue was diluted with double-distilled water to 50 mL and measured

by using flame atomic absorption spectrometry (VARIAN, AA 240). The concentration of Cd was calculated in terms of per ml for water and per gram dry weight for sediment, unio, fish and pistia.

Cd removal efficiency of ecosystem (i.e, Ecosystem efficiency) was determined calculating the reduction of Cd concentration in water using the following formula:

$$EE = \frac{Cd_i - Cd_f}{Cd_i} \times 100$$

Where, EE = Ecosystem efficiency

Cd_i = Initial concentration of Cd in water (after application of $CdCl_2$)

Cd_f = Final concentration of Cd in water

The rate of accumulation of Cd by employed different components of ecosystem was estimated as component efficiency. The component efficiency was written as α . δ is designated for Cd content in components, then initial and final content were represented as δ_i and δ_f , respectively. t was depicted as time, then final and initial time represented as t_f and t_i , respectively. The component efficiency in respect to Cd accumulation can also be expressed by the following formula:

$$\alpha = \frac{\delta_f - \delta_i}{t_f - t_i}$$

All results obtained from the aquariums were statistically interpreted. A one way ANOVA (Gomez and Gomez, 1984) was used to compare the treatment means. Before analysis, the assumptions of normal distributions and homogeneity of the variance were checked using

Kolmogorov-Smirnov and Cochran's tests, respectively. If the main effect was found to be significant, the ANOVA was followed by a LSD (least significance difference) test. All statistical tests were performed at 5% probability level using statistical package EASE and M-STAT.

3. Results

3.1. Cd in water

Concentration of Cd in water ranged from 0.001 – 2.0 mg/L. There was a significant system difference (ANOVA; $P < 0.05$) in mean final values of Cd showing the trend of variation as follows: $ES_1 > ES_2 > ES_3 > ES_4 > ES_5$. The highest mean final value (0.180 mg/L) of ES_1 was 2.16, 3.24, 6.38 and 30 times higher than that of the ES_2 , ES_3 , ES_4 and ES_5 , respectively (Table 1). Temporal course of variation in the Cd concentration showed a gradual declining trend in all system (Fig. 2). The decreasing rate was maximum in ES_5 and minimum in ES_1 .

3.2. Cd in sediment

The Cd content of sediment varied (0.002 – 0.0176 mg/g) significantly (ANOVA; $P < 0.05$) in all the systems employed. The mean final value was maximum (0.0175 mg/g) in the ES_1 exhibiting the following order of variations: $ES_1 > ES_2 > ES_3 > ES_4 > ES_5$ (Table 1). The concentration of Cd in ES_1 was 12, 36, 186 and 326% higher compare to that of ES_2 , ES_3 , ES_4 and ES_5 , respectively. The Cd concentration of soil gradually increased (105 to 340%) with time (Fig. 2).

3.3. Cd in unio (*Lamellidens marginalis*)

The accumulated Cd in unio varied between 0.004 and 0.079 mg/g in different systems. The maximum final concentration of Cd (0.079 mg/g) in ES₂ revealed 18, 49 and 53% higher value than that of ES₃, ES₄ and ES₅, respectively (Table 1). Temporally the concentration of Cd exhibited an increasing trend over time that ranged from 1220 to 1600% in all systems (Fig. 2).

3.4. Cd in tilapia (*Oreochromis mossambicus*)

The concentration of Cd in fish tissue of ES₃ and ES₅ ranged from 0.002 – 0.0076 mg/g. There was a significant difference (ANOVA; $P < 0.05$) in the mean final content of Cd in two systems and registered 130% higher value in ES₃ than that of the ES₅ (Table 1). Time course variation was also similar as that of the Unio (Fig. 2).

3.5. Cd in pistia (*Pistia stratiotes*)

Cd content of plant tissue ranged from 0.005 to 0.725 mg/g in ES₄ and ES₅. The mean final Cd content (0.724 mg/g) in ES₄ pronounced 1.17 times elevated value compared to that of the ES₅. As time progressed, both ES₄ and ES₅ system revealed a sharp increasing trend (Fig. 2).

3.6. Cd removal efficiency

Ecosystem efficiency varied from 90 to 99.5% and showing increasing trend with increasing number of ecosystem components (Fig. 4). Component efficiency (i.e, rate of Cd accumulation) also ranged from 0.075 to 0.44×10^{-3} mg/g/d, 1.7 to 2.6×10^{-3} mg/g/d, 0.04 to 0.198×10^{-3} mg/g/d and 21.9 to 25.5×10^{-3} mg/g/d in sediment, unio, tilapia and pistia, respectively in

different ecosystem (Fig. 3). Unlike ecosystem efficiency, component efficiency showed a reverse response with the increasing number of ecosystem components.

4. Discussions

Final Cd concentrations of water pronounced by 0.18, 0.083, 0.055, 0.028 and 0.006 mg/L from the highest concentration 2 mg/L (just after application of Cd) in ES₁, ES₂, ES₃, ES₄ and ES₅, respectively. Results obtained from the study also demonstrated that mean substantial reduction of Cd varied between 1.820 to 1.994 mg/L in different simulated ecosystem (Fig. 3). Above resultant data clearly revealed a system dependent sharp reduction of Cd was by means of differential functional efficiency factors of ecosystem and its components.

4.1. Ecosystem efficiency

Systems efficiencies of Cd removal were 5%, 8%, 9% and 11% higher in ES₂, ES₃, ES₄ and ES₅, respectively than that of the ES₁ which suggested a cumulative effect of increasing number of components employed in different simulated aquatic ecosystem significantly facilitated the process of Cd concentration reduction in water column. Relationship between the ecosystem efficiency (SE) of Cd removal and number of ecosystem component employed showed that ecosystem efficiency was improved with increasing number of component which also strongly implying a synergistic effect of all ecosystem components has a high potential Cd withdrawn mechanism from water column in ES₅ (Fig. 4). However, it is of fundamental importance to the longer term availability and sustainable management of water resources that the maintenance of ecosystems and the strengthening of their role as providers of services and goods is recognized (Laanbroek et al., 1996).

4.2. Component efficiency in different systems

Sediment of ES₁ showed 15 - 486% higher absorption efficiency than that of the remaining four systems. Out of four systems (ES₂, ES₃, ES₄ and ES₅), Cd accumulation efficiency of unio was maximum (0.26%) in ES₂ system. Tilapia of ES₃ exhibited 5 times higher accumulation of Cd compared to ES₅, whereas pistia in ES₄ pronounced 1.2 times elevated value of Cd accumulation efficiency compared to that of the ES₅. Above data strongly implied that each component might have a differential performance in Cd accumulation in different simulated ecosystem (Fig. 3). A reverse relationship was also found between the Cd removal component efficiency (CE) and number of ecosystem component which also clearly demonstrated that component efficiency decreased with increased number of ecosystem component (Fig. 2). Individual and population patterns of bioaccumulation were analyzed by comparing the simulated results of five different scenarios of dissolved metal concentrations (Simas et al., 2001).

4.3. Component efficiency within the systems

In ES₁, sediment showed 340% absorption, whereas maximum efficiency of Cd accumulation in unio was 4 – 5.1 and 4 – 4.6 times higher in ES₂ and ES₃, respectively and pistia exerted 11 – 204 and 10 – 119 times highest potential of Cd accumulation in ES₄ and ES₅, respectively among the other components employed in five respected simulated ecosystems with various combinations of components. It therefore, may be concluded considering the above results; ecosystem components showed a variable performance and pistia was efficient component in Cd uptake point of view (Fig. 3). It was studied that the aquatic plants are

responsible for fast metal abatement from aquatic environment (Rai et al., 1995 and Das and Jana, 1999) and the arsenate removal efficiency of pistia (*Pistia stratiotes* L.) is maximum (87.5%) at pH 6.5 (Mukherjee and Kumar, 2005).

5. Conclusion

On account of the above discussion, it may be concluded that though, Cd accumulation by the sediment plays an important role to decrease the Cd level of water in ES₁ system in one hand, whereas, Cd uptake and finally differential accumulation in the tissue of aquatic organism was the potential factors for declining the Cd concentration of water in remaining systems (ES₂ – ES₅) on the other hand, but their efficiency of accumulation varied with respect to different systems carrying various composition of components. Transport of metals into the intracellular section aided by either diffusion of the metal ion across the cell membrane or by active transport by a carrier protein (Brezonik et al., 1991 and Wepener et al., 2001). Moreover, in this connection, it was obvious that ecosystem components serve as a physical and biological buffer to minimize the heavy metal load in water column. Coastal wetlands ecosystems, such as salt marshes and mangroves, also function as buffers and regulators of water quality (Koch et al., 1992).

In the present study, overall explanation of the results affords to draw a conclusion that - (1) The Cd removal from water column of an ecosystem largely depends on performance/efficiency of the ecosystem which is improved by numerical manipulation - i.e., increase the number of ecosystem components and compositional manipulation – i.e., selective employment of ecosystem components of different trophic level. (2) Individual component efficiency was increased when single trophic component were employed and decreased when the different

trohic components are present in an ecosystem. (3) Among the employed different components the component efficiency of pistia pronounced its best performance and contributed maximum part to remove the Cd from water column in an ecosystem. According to De Groot (1992), Ecosystem functions are defined as the capacity of natural processes and components of natural or semi-natural systems to provide services and goods that satisfy human needs (directly or indirectly). Finally, it may be proposed from the study that ‘manipulating numerical and compositional structure of components-related ecosystem’ is an efficient model of ecosystem to remove as well as to over come the toxicity problems of Cd, other heavy metals and various nutrients in the aquatic environment.

Acknowledgement

We are thankful to Prof. P. K. Bandyopadhyay who extended his kind cooperation providing laboratory facilities and also grateful for his valuable contribution to the research work

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Table 1. Mean final values ($\pm$ S.E.) of Cd in different components under different simulated ecosystems employed. Same script among systems (rows) revealed lack of significant difference.

Components	Ecosystem Systems				
	ES ₁	ES ₂	ES ₃	ES ₄	ES ₅
Water (mg/L)	0.180 ^A ± 0.032	0.083 ^B ± 0.03	0.0554 ^C ± 0.03	0.0282 ^D ± 0.008	0.006 ^E ± 0.002
Soil (mg/g)	0.0175 ^A ± 0.004	0.0158 ^B ± 0.0034	0.0129 ^C ± 0.0033	0.0061 ^D ± 0.001	0.0041 ^E ± 0.0005
Unio (mg/g)	-	0.079 ^A ± 0.01	0.067 ^B ± 0.015	0.053 ^C ± 0.011	0.0518 ^C ± 0.009
Tilapia (mg/g)	-	-	0.0076 ^A ± 0.0008	-	0.0033 ^B ± 0.00071
Pistia (mg/g)	-	-	-	0.724 ^A ± 0.05	0.691 ^B ± 0.04

Legends to figures

Fig. 1. Experimental design showing the five different simulated aquatic ecosystems used.

Fig. 2. Temporal responses of Cd content in water and Cd uptake by ecosystem components in different simulated ecosystems. Arrow ($\rightarrow$) indicatig the time of addition of Cd in water.

Fig. 3. Component efficiency (i.e, rate of Cd uptake) criteria of different components in five ecosystems during the period of experimentation. Inset showing decreasing of Cd concentration in water column with increasing number of components. Same script in the same component bars of different systems revealed lack of significant difference.

Fig. 4. Relationship between the ecosystem efficiency and number of ecosystem component.

Figure 1. Experimental design showing the five different simulated aquatic ecosystems used

Fig. 2.

Temporal responses of Cd content in water and Cd uptake by ecosystem components in different simulated ecosystems. Arrow (➡) indicatig the time of addition of Cadmium in

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