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Partitioning and Bioaccumulation of Cadmium from the Sediment of Brackishwater Ponds in Sundarban, India

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Abstract

Sediment samples from 12 brackishwater ponds in Sundarban, India, showed cadmium (Cd) levels of 2.6-6.7 $mg \cdot kg^{-1}$. When these sediment samples were overlain with Cd-free water in the laboratory, Cd partitioned from the sediment into the water and reached concentrations of 0.08-0.54 $mg \cdot l^{-1}$. The extent of partitioning was not proportional to the amount of Cd in the sediment. The presence of common carp juveniles and tubificid worms did not influence the partitioning rate, but Cd concentrations in the water were significantly lower when these organisms were present. Both common carp juveniles and tubificid worms accumulated Cd, the fish more than the worms.

Introduction

Intense activity in the industrial and agriculture sectors have inevitably increased the levels of heavy metals in many natural waters. The brackishwater ponds in Sundarban, India, have not been spared (Das et al. 1994). A large part of the metals that come into the water are subsequently immobilized by precipitation, ion exchange or adsorption (Tessier et al. 1979), but several physical and chemical factors can remobilize heavy metals from suspended materials and sediment (Samanidou and Fytianos 1990). The factors that control sedimentation of metals and its reentry into the water column are complex and incompletely understood. One question is whether metals that have been sedimented are completely immobilized or may return to a dissolved phase to become biologically available again. The present study documents the partitioning of cadmium (Cd) from the sediment of brackishwater ponds in Sundarban and the bioaccumulation in aquatic organisms.

Materials and Methods

Samples of sediment were collected from 12 ponds spread over two districts (North and South 24 Parganas) of Sundarban in India. Samples of 15-cm deep sediment were collected at random from three locations in each pond, usually under 1-m deep water. Samples were wrapped in clean polythene bags and immediately brought to the laboratory. Samples of surface water were also collected from each pond. Water samples were acidified and brought to the laboratory in clean acid-washed polythene vials.

In the laboratory, about 5 g subsamples were taken from each sediment sample and dried in an oven at 105°C for 72 h. The dry subsamples were finely ground and 1 g of each was digested in strong nitric acid and hydrochloric acid (Van Loon 1980). Cd in the digested sample was measured with an atomic absorption spectrophotometer (Varian AA-1475). Cd in the water sample was also measured with the same instrument after filtering the water through Whatman filter paper (No. 1) and digesting it by strong $HN0_3$. The minimum concentration of Cd that could be detected was approximately 0.001 $mg{\cdot}l^{-1}$. A deuterium lamp provided background correction of non-atomic interferences during determination. The accuracy of determination was checked periodically by repeated analyses of subsamples prepared from the standard. The 12 original sediment samples were used directly for the experiment in the laboratory. The experiments were done for 96 h in 36 glass jars of 3-l capacity. The 12 samples in three replicates each were arranged according to a complete randomized design recommended for laboratory experiments (Gomez and Gomez 1984). Each jar was filled with about 1-cm deep sediment and an overlying 2.5 l of Cd-free water (pH 7.8, total alkalinity 120 $mg{\cdot}l^{-1}$ as $CaC0_3$, hardness 160 $mg{\cdot}l^{-1}$ as $CaC0_3$, temperature 25°C). The sediment-to-water ratio (weight per volume) was 1:20 for each jar. One set of 12 jars was stocked with five properly acclimated juveniles of common carp *Cyprinus carpio* ($L=3.0 \pm 0.10$ cm, $W=0.50 \pm 0.05$ g), another set of 12 jars each with 2.5 g (wet weight) of the tubificid worm *Branchiura sowerbyi*, and the third set without animals. After 96 h of exposure, Cd was estimated in the filtered water and whole bodies of common carp juveniles and worms. The bioconcentration factor (BCF) was calculated as:

$$BCF = \frac{\text{Total Cd in animal}}{\text{Dissolved Cd in water}}$$

The whole experiment was repeated three times.

The pH and conductivity of the sediment samples were measured, respectively, with an electronic digital pH meter (Systronics, India) and a digital direct reading conductivity meter (Systronics, India) after diluting the sediment samples with deionized water (1:20 weight per volume). Mean pH and conductivity of the sediment samples are shown in Table 1.

Table 1. pH and conductivity of sediment soil with mean ± SD values.

Pond no.	pH	Conductivity ($x\ 10^{-2}$ mMho)
1	8.48 ± 0.04	0.47 ± 0.02
2	8.32 ± 0.19	0.40 ± 0.04
3	8.77 ± 0.18	0.30 ± 0.03
4	8.18 ± 0.08	0.35 ± 0.04
5	8.11 ± 0.08	0.40 ± 0.01
6	8.41 ± 0.11	0.33 ± 0.05
7	8.00 ± 0.07	0.47 ± 0.05
8	8.37 ± 0.13	0.25 ± 0.04
9	7.90 ± 0.01	0.63 ± 0.01
10	7.94 ± 0.01	0.61 ± 0.01
11	7.96 ± 0.01	0.77 ± 0.01
12	7.99 ± 0.02	0.51 ± 0.01

Data were tested by single-factor ANOVA. Comparison between any two means was done by test of Least Significant Difference (LSD) and evaluations were made at 5% level of probability (Gomez and Gomez 1984).

Results

The pH of the sediment samples varied significantly (ANOVA $F_{11,24}$ =46.63; $P<0.01$, Table 1). The conductivity of the sediment samples also varied significantly (ANOVA $F_{11,24}$=61.44; $P<0.01$) indicating variations in anionic strength. Cd could not be detected in the surface water of ponds 1-4. In ponds 5-12, Cd concentration in pond water was 0.02-0.25 $mg \cdot l^{-1}$.

Cd present in the sediment of the brackishwater ponds partitioned from the sediment in the overlying water and was accumulated by fish and tubificid worms. Table 2 shows the amount of Cd detected in the sediment samples and in the test water overlying the sediment. The concentration of Cd in the sediment was 2.6-6.7 $mg \cdot kg^{-1}$, and in water without the presence of fish or worms 0.08-0.54 $mg \cdot l^{-1}$. Cd concentration in the water was not proportional to that in the sediment, thus indicating a difference in the extent of partitioning of the metal among the sediment samples. Except in the sediment samples of ponds 9 and 11, Cd concentrations were significantly higher in test water with neither common carp juveniles nor tubificid worms (ANOVA, Table 2). Cd concentrations in water with common carp and tubificid worms showed no significant difference (LSD test) except in the sediment samples of ponds 7, 10 and 12, in which the test water with worms showed higher Cd concentration than the water with fish. Bioaccumulation of Cd in juvenile common carp and tubificid worms is shown in Table 3. Both worms and juvenile fish accumulated high Cd concentrations. Common carp accumulated significantly higher Cd concentrations than the tubificid worms, except in sediment samples of ponds 1-4 (LSD test, Table 3). Bioconcentration factor (BCF) was 63-931 in common carp and 10-953 in the worms. A negative correlation was found between conductivity of soil and BCF of common carp ($r=0.60$, $P<0.05$) or worms ($r=0.55$, $P<0.05$).

Table 2. Partitioning of Cd from sediment into water. Values are mean of three samples ± SD. Different letters in horizontal row indicate significant difference (LSD) at $P<0.05$.

Pond no.	Total Cd ($mg \cdot kg^{-1}$) in sediment	Dissolved cadmium ($mg \cdot l^{-1}$) in water		
		No animal	With carp	With worms
1	6.64 ± 3.49	0.08 ± 0.01^b	0.04 ± 0.005^a	0.05 ± 0.002^a
2	5.29 ± 2.09	0.12 ± 0.02^b	0.05 ± 0.003^a	0.06 ± 0.002^a
3	5.76 ± 3.23	0.11 ± 0.03^b	0.03 ± 0.004^a	0.05 ± 0.009^a
4	5.69 ± 2.33	0.17 ± 0.01^b	0.01 ± 0.006^a	0.01 ± 0.006^a
5	4.31 ± 0.77	0.18 ± 0.01^b	0.05 ± 0.012^a	0.04 ± 0.014^a
6	4.77 ± 1.02	0.42 ± 0.03^b	0.09 ± 0.003^a	0.13 ± 0.026^a
7	5.53 ± 1.64	0.54 ± 0.02^b	0.02 ± 0.007^a	0.17 ± 0.008^c
8	6.69 ± 1.27	0.10 ± 0.02^b	0.02 ± 0.011^a	0.01 ± 0.003^a
9	2.88 ± 0.08	0.12 ± 0.05^a	0.06 ± 0.018^a	0.09 ± 0.003^a
10	4.59 ± 0.26	0.12 ± 0.02^b	0.07 ± 0.006^a	0.17 ± 0.004^c
11	4.03 ± 0.18	0.10 ± 0.03^a	0.08 ± 0.001^a	0.10 ± 0.004^a
12	2.59 ± 0.28	0.12 ± 0.03^b	0.03 ± 0.012^a	0.08 ± 0.008^b

Table 3. Whole body concentration of Cd ($\mu g \cdot g^{-1}$) and bioconcentration factors in common carp juvenile and tubificid worms exposed over Cd-contaminated sediment soil.

Sediments from pond no.	Cd ($\mu g \cdot g^{-1}$) ± SD		Bioconcentration factors	
	Carp	Worms	Carp	Worms
1	16.19 ± 3.95	8.57 ±0.47	408	154
2	11.07 ± 1.33	9.83 ± 0.45	206	164
3	10.80 ± 3.85	10.50 ± 2.51	325	220
4	7.70 ± 2.29	6.70 ± 2.20	931	953
5	11.69 ± 2.03	4.37 ± 0.77	287	117
6	9.94 ± 0.47	4.07 ± 1.78	216	31
7	6.84 ± 1.93	2.83 ± 1.62	642	16
8	7.77 ± 0.74	3.59 ± 1.55	730	616
9	6.30 ± 0.91	2.12 ± 0.37	117	23
10	5.27 ± 1.09	1.71 ± 0.94	70	10
11	5.03 ± 0.31	2.60 ± 0.33	63	27
12	6.31 ± 1.15	2.10 ± 0.75	312	25

Discussion

The results of this study indicate that a large part of the Cd in sediments is loosely bound and could be easily partitioned into overlying water. Such loosely bound Cd in the sediment indicates an anthropogenic source of metal contamination of the ponds. Few reports are available on the deposition of Cd in the aquatic ecosystem of Sundarban. Chattopadhyay and Saha (1982) observed that brackishwater ponds of Sundarban showed a tendency to accumulate elements like Fe, Mn, Cu and Zn, due to use of seawater which contained these elements in considerable quantity. In recent years a few workers indicated that metals like Cd, Zn, Cu and Pb might be carried to different parts of Sundarban from the adjacent cities of Calcutta, Howrah and Haldia through networks of the Hoogly estuary (Mitra and Choudhury 1993; Mitra et al. 1995).

Cd concentrations in the sediments of some ponds in Sundarban reported by Das et al. (1994) are within the range tested here (2.59-6.69 $mg{\cdot}kg^{-1}$). However, the extent of partitioning of Cd from the sediment into the overlying test water was not proportional to the total amount of Cd in the sediment. The mobility of metal between the solid and aqueous phases in the aquatic ecosystem depends upon several physical and chemical factors. During resuspension of sediment, the mobility of Cd may be increased by a shift from reducing to oxidizing conditions and by altered pH (Khalid et al. 1981; Förstner 1987). Unlike Cr, Fe, Al, etc., Cd does not readily form insoluble hydroxides in water. But depending on the predominance of anionic species in solution, Cd can form complexes with chloride, sulfate, sulphide, bicarbonate, etc. The chlorides and sulphides of metals are not readily soluble (Förstner and Wittmann 1983). Mobility of metals in soil was found to be greatly influenced by the conductivity or anionic strength of the soil (Olaniya et al. 1992). Present results indicate an inverse relationship between the bioconcentration factor and conductivity of soil. The texture of the soil (Olaniya et al. 1992), and ratio of sediment to water are also important factors which regulate the resuspension of sediment particles and partitioning of metals from sediments. The ponds under study had much larger sediment-to-water ratios than were used in our laboratory experiment. Under natural conditions, the sedimentation process may prevent resuspension of sediment particles, and Cd that is partitioned into water may also be diluted in the large volume of water.

An interesting feature of this study was that bioturbation did not enhance the partitioning of Cd from the sediment. Bioturbation enhances resuspension of sediment (Campbell et al. 1988). Bioturbation caused by benthic invertebrates (Bostrom et al. 1982) or benthic fish (Andersson et al. 1978) is known to contribute to the mineralization of dissolved and particulate compounds in pond sediments. Jana and Das (1992) found that to induce a significant release of fertilizer from the sediment in a 3-l glass jar, at least eight juvenile common carp, each weighing about 2.8 g, was necessary. When we used such a high biomass it caused large scale mortality, particularly of worms probably because of contaminated sediments. So we used five juveniles, each weighing about 0.5 g, for each 3-l glass jar. Almost an equal weight (total) of worms was used for each glass jar. It appeared that the number and biomass of the fish and worms were insufficient to effect a resuspension of the sediment particles and partitioning of Cd from the sediment in the present study. But the organisms accumulated Cd at a high rate and total Cd of water reduced. Common carp juveniles accumulated more Cd obviously due to greater surface area.

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