Evaluation of Cadmium Concentrations in the Surface Sediments of Salt River Estuary, Taiwan

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Abstract

Major objectives of this study are to evaluation the pollution and potential ecological risk of cadmium (Cd) in the sediments of Salt River estuary, Taiwan. Nine monitoring stations were installed near the estuary of Salt River to collect sediment samples for analyzing Cd. Results of laboratory analyses show that contents of Cd in the sediments are between 0.25 and 2.54 mg/kg with an average of 1.05±0.85 mg/kg. The spatial distribution of Cd reveals that the Cd concentration is relatively high near the river mouth, and gradually diminishes toward the harbor region. This indicates that upstream industrial and municipal wastewater discharges along the river bank are major sources of pollution. Results from the enrichment factor analysis imply that the sediments can be characterized as minor to severe degree of Cd enrichment. Results of geo-accumulation index analysis indicate that the sediments can be characterized as moderate degree of Cd accumulation. Results of potential ecological risk index indicate that the sediments at Salt River estuary have high to serious ecological potential risk.

Keywords: Cadmium, Ecological Risk, Enrichment Factor, Geo-accumulation Index, Sediment.

1. Introduction

Salt River is approximately 5 km long, and drains a catchment of less than 12 km^2. The river flows through the Linhai Industrial Park and China Steel Plant (the largest steel plant in Taiwan) and finally discharged into Kaohsiung Harbor (Fig. 1). In the Linhai Industrial Park, there are more than 482 registered industrial factories that discharge their treated wastewater into the Salt River. Results from recent investigation indicate that the Kaohsiung Harbor is heavily polluted, and the Salt River is one of the major pollution sources [1]. The river received untreated municipal and industrial wastewater discharges causing serious deterioration of the river water quality and the environmental quality near the river estuary to threaten the water environmental ecological system seriously.

Cadmium (Cd) is extremely toxic to most plants and animal species [2-4]; its presence threatens the water ecological environment. Therefore, much research effort has been directed toward the distribution of Cd in water environment. Anthropogenic activities including municipal wastewater discharges, agriculture, mining, fossil fuels, and discharges of industrial wastewater are the major source of Cd pollution [4]. Cadmium has low solubility in aqueous solution; it is easily adsorbed on water-borne suspended particles. After a series of natural processes, the water-borne Cd finally accumulates in the sediment, and the quantity of Cd contained in the sediment reflect the degree of pollution for the water body [5]. The objective of this study is to investigate the Cd distribution in the surface sediment near Salt River estuary so that the degree of Cd accumulation and potential ecological risk can be evaluated.

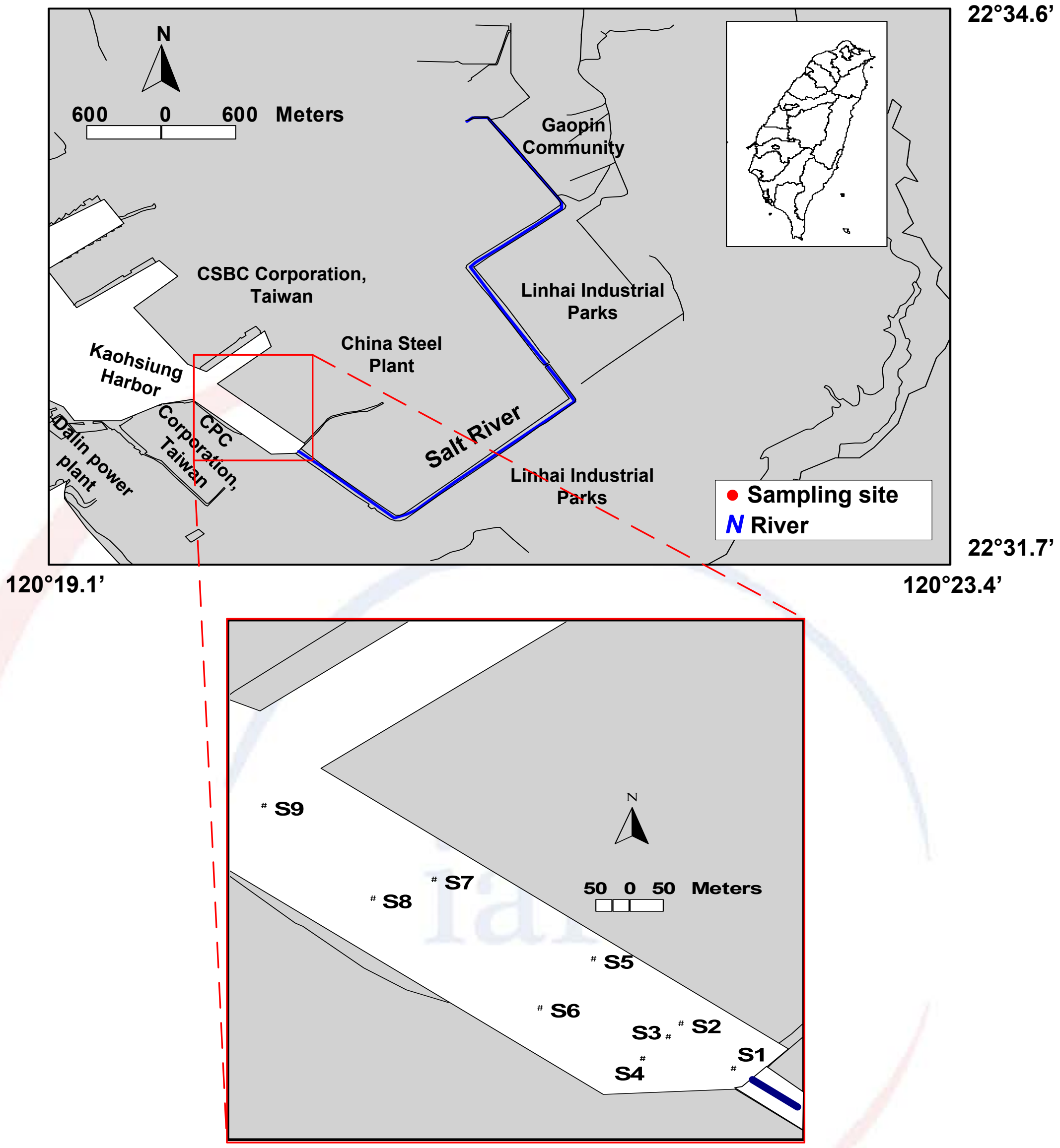

Figure 1. Map of the study area and sampling locations.

2. Materials and Methods

Surface sediment samples were collected at nine stations near Salt River estuary (Figure 1) with Ekman Dredge Grab aboard a fishing boat. The sampling stations, sample collection, and characteristics of the sediment (e.g. particle size and organic matter (OM)) have been reported in detail previously [6]. For Al and Cd analyses, the sediments were screened through 1 mm nylon net to remove particles with diameters larger than 1 mm. 0.5 g dry weight of the sediment sample was mixed with a mixture of ultra-pure acids (HNO_3:HCl:HF = 5:2:5), and was then heated to digest. The digested sample was filter through 0.45 μm filter paper; the filtrate was diluted with ultra-pure water to a pre-selected final volume. The Al and Cd contents were determined using a flame atomic absorption spectrophotometry (Hitachi Z-6100).

Statistical data analyses include average, standard deviation, maximum and minimum. In this study, the enrichment factor (EF) and geo-accumulation index (I_{geo}) were applied to evaluate the degree of Cd pollution and the associated potential ecological risk index (PERI). EF is defined as: $EF = (X/Al)_{sediment}/(X/Al)_{crust}$, where *(X/Al)* is the ratio of Cd to Al. The average Cd and Al content in the earth crust were 0.2 mg/kg and 8.23%, respectively, that excerpted from the data published by Taylor (1964) [7]. The I_{geo} is defined as [8]: $I_{geo} = log_2 (C_n/1.5B_n)$, where C_n is the measured content of element Cd, and B_n is the background content of Cd 0.2 mg/kg, in the average shale [7]. Factor 1.5 is the background matrix correction factor due to lithogenic effects. The potential ecological risk index PERI is defined as [9]: $PERI = PI \times T_i$, where PI *(pollution index)* $= (C_i/C_f)$; C_i is the measure concentration of Cd in sediment; C_f is the background concentration of Cd; T_i is its corresponding coefficient, i.e. 30 for Cd [9]. In this study, the average Cd content in earth crust of 0.2 mg/kg [7].

3. Results and Discussion

3.1 Distribution of Cadmium in Sediments

Contents of Al in the sediment of Salt River estuary are between 3.34 and 5.8% with an average of 4.95±0.72%. All sediment samples collected at Salt River estuary contain 0.25–2.54 mg/kg of Cd with an average of 1.05±0.85 mg/kg (Figure 2). Concentration distributions of Cd in Salt River estuary sediment shown in Figure 2(b) reveal that the sediment Cd content is relatively higher near the boundary of the river estuary, and gradually decreases in the direction toward the harbor. Because Salt River is subject to upstream discharges of treated and un-treated domestic and industrial wastewaters, the pollutants are transported by river flow and finally accumulate near the river estuary. Some pollutants may drift with sea current to be dispersed into open sea.

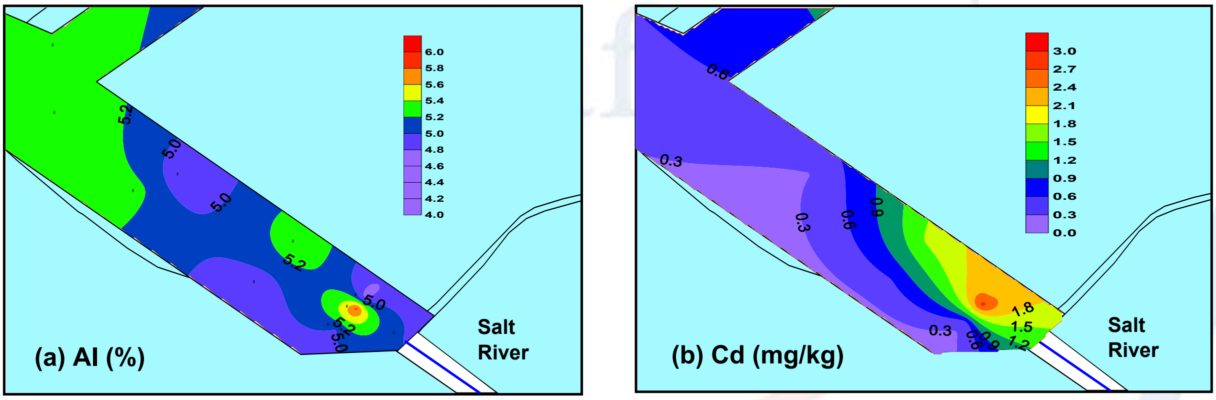

Figure 2. Contour map of Al (a) and Cd (b) contents in the surface sediments of Salt River estuary.

3.2 Enrichment Factor

The enrich factor (EF) is a useful tool for differentiating the man-made and natural sources of metal enrichment [1,10]. This evaluating technique is carried out by normalizing the metal concentration based on geological characteristics of sediment. Al is a major metallic element found in the earth crust; its concentration is somewhat high in sediments and is not affected by man-made factors. Thus, Al has been widely used for normalizing the metal concentration in sediments [1,10]. When the EF of a metal is greater than 1, the metal in the sediment originates from man-made activities, and vice versa. The EF value can be classified into 7 categories [17]: 1, no enrichment for EF < 1; 2, minor for 1 < EF < 3; 3, moderate for 3 ≤ EF < 5; 4, moderately severe for 5 ≤ EF < 10; 5, severe for 10 ≤ EF < 25; 6, very severe for 25 ≤ EF < 50; and 7, extremely severe for EF ≥50. Table 1(a) show EF values of the sediment Cd for the Salt River estuary region; the Cd concentration is consistent with the Cd EF value for all sampling sites, and all EF values are greater than 1. This indicates that the sediment Cd has enrichment phenomenon with respect to the earth crust and that all Cd originates from man-made sources. Sites S1, S2 and S3 are classified as severe enrichment, Sites S5, S6 and S9 are classified as moderate enrichment, and the other Sites are classified as minor enrichment. These results point out that the sediment near the river mouth experiences severe enrichment of Cd that originates from the upstream sources of pollution. Additionally, the average EF value of 8.3 obtained in this study is lower than the average EF value of 11.4 reported earlier [1] indicating that the upstream pollution has been reduced so that the accumulation of pollutants in sediments is not as serious as during earlier years. This observation may show the effectiveness of intercepting the Salt River flow and dredging the river estuary.

Table 1. EF, I_{geo}, PI, and PERI of Cd for each station studied at Salt River estuary

Site	(a) Enrichment factor			(b) Geo-accumulation index			(c) Potential ecological risk		
	EF value	EF class	EF level	I_{geo} value	I_{geo} class	I_{geo} level	PI	PERI	Risk level
S1	11.5	5	severe	2.2	3	moderately strong	18	525	serious
S2	17.4	5	severe	2.7	3	moderately strong	25	750	serious
S3	17.8	5	severe	3.1	4	strong	32	951	serious
S4	2.9	2	minor	0.2	1	none to medium	4	131	higher
S5	11.8	5	moderate	2.4	3	moderately strong	19	581	serious
S6	4.6	3	moderate	0.9	1	none to medium	7	206	high
S7	2.6	2	minor	0.0	1	none to medium	4	113	higher
S8	2.0	2	minor	-0.3	0	none	3	94	higher
S9	3.8	3	moderate	0.7	1	none to medium	6	188	high
Mean	8.3	4	moderately severe	1.3	2	moderate	13	393	serious

3.3 Geo-accumulation Index

Similar to metal enrichment factor, index of geo-accumulation (I_{geo}) can be used as a reference to estimate the extent of metal accumulation. The I_{geo} value can be classified into 7 classes: 0, none for I_{geo} <0; 1, none to medium for I_{geo} = 0–1; 2, moderate for I_{geo} = 1–2; 3, moderately strong for I_{geo} = 2–3; 4, strong for I_{geo} = 3–4; 5, strong to very strong for I_{geo} = 4–5; and 6, very strong for I_{geo} >5. Based on the I_{geo} data and Müller's (1979) [8] geo-accumulation indexes, the accumulation levels with respect to Cd at each station are ranked in Table 1(b). Sites S1-S3, and S5 are classified as either strong or moderately strong accumulation, Sites S8 is classified as none accumulation, and the other Sites are classified as none to medium accumulation.

3.4 Potential Ecological Risk

The potential ecological risk index (PERI) is applied to evaluate the potential risk associated with the accumulation of Cd in surface sediments. PERI that was proposed by Hakanson (1980) [9] can be used to evaluate the potential risk of one metal or combination of multiple metals. The calculated PERI values can be categorized into 5 classes of potential ecological risks [9]: low risk (PERI < 40), moderate risk (40 ≤ PERI < 80), higher risk (80 ≤ PERI < 160), high risk (160 ≤ PERI < 320), and serious risk (PERI ≥ 320). Table 1(c) lists the PI value, PERI value, and risk classification for the Cd contained in the surface sediment samples collected near Salt River estuary. All nine stations are classified between high to serious risk with respect to Cd pollution. The above evaluation results indicate that the Cd contained in surface sediments at Salt River mouth has serious potential ecological risks. Therefore, effective management and control of upstream pollution should be immediately implemented in order to improve the river mouth sediment quality and lower the associated ecological risk.

4. Conclusions

The sediment samples collected at Salt River estuary contain 0.25–2.54 mg/kg of Cd with an average of 1.05±0.85 mg/kg. The distribution of Cd in sediment reveals that the Cd originates from the river upstream discharges of industrial and domestic wastewaters; it is transported along the river and finally deposited and accumulated near the river estuary. Results of EF analysis indicate that the Salt River estuary sediments were minor to severe enrichment with Cd. Compared to the EF value of 11.4 reported earlier [1], the degree of Cd enrichment at Salt River estuary has been obviously reduced. This may be associated with river renovation and river estuary dredging. Results of I_{geo} analysis show that the Salt River estuary sediments were moderate accumulation with Cd. Results of potential ecological risk evaluation show that the classification of potential ecological risk for the sediment Cd at Salt River estuary is between high to serious. The results can provide regulatory valuable information to be referenced for developing future strategies to renovate and manage river estuary and harbor.

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