Enrichment, Accumulation and Ecological Risk Evaluation of Cadmium in the Surface Sediments of Jen-Gen River Estuary, Taiwan

Cheng-Di Dong, Chih-Feng Chen, Ming-Sheng Ko, and Chiu-Wen Chen

Abstract—**Major objectives of this study are to evaluation the enrichment, accumulation, and potential ecological risk of cadmium (Cd) in the sediments of Jen-Gen River estuary, Taiwan. Eleven sampling locations were installed near the mouth of Jen-Gen River to collect sediment samples for analyzing Cd. Results of laboratory analyses show that contents of Cd in the sediments are between 0.20 and 4.65 mg/kg with an average of 1.26±1.23 mg/kg. The spatial distribution of Cd reveals that the Cd concentration is relatively high in front of the river mouth. 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 none to strong degree of Cd accumulation. Results of potential ecological risk index indicate that the sediments at Jen-Gen River estuary have high ecological potential risk.**

Index Terms—**Cadmium, ecological risk, enrichment factor, geo-accumulation index, sediment.**

I. Introduction

The metals generated by anthropogenic activities cause more environmental pollution than naturally occurring metals. After entering a water body, heavy metals will be carried over to sea so that the river estuary and regions along seashore become the ultimate resting place for these metals being transported in the environment. Hence, the river estuary region, harbor and seashore with dense population and industries usually become heavily polluted by toxic metals.

Cadmium (Cd) is extremely toxic to most plants and animal species [1]; 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 [2]. 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 [3], [4].

Jen-Gen River flows through a southern Taiwan industrial city (Kaohsiung City). In previous years, the river received untreated municipal and industrial wastewater discharges causing serious deterioration of the river water quality and the environmental quality near the river mouth to threaten the water environmental ecological system seriously. The objective of this study is to investigate the Cd distribution in the surface sediment near Jen-Gen River estuary so that the degree of Cd enrichment, accumulation and potential ecological risk can be evaluated.

II. Materials and Methods

Surface sediment samples were collected from 11 sampling sites near Jen-Gen River mouth (Fig. 1) in May 2009 using an Ekman Bridge Grab Sampler (6" × 6" × 6") manufactured by Jae Sung International Co., Taiwan. The sampling locations, sample collection and characteristics of the sediment (e.g. particle size and organic matter) have been reported in detail previously [5].

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, Japan).

Each batch of analyses was accompanied with a standard reference (marine sediment (PACS-2)) and a blank. For every 5 samples analyzed, the examination of standard solutions was carried out to assure the stability of the instrument used. The standard reference of marine sediment (PACS-2) was found to contain 2.01±0.18 mg/kg in our lab that is close to the certified values of 2.11±0.0.15 mg/kg (*n*=3).

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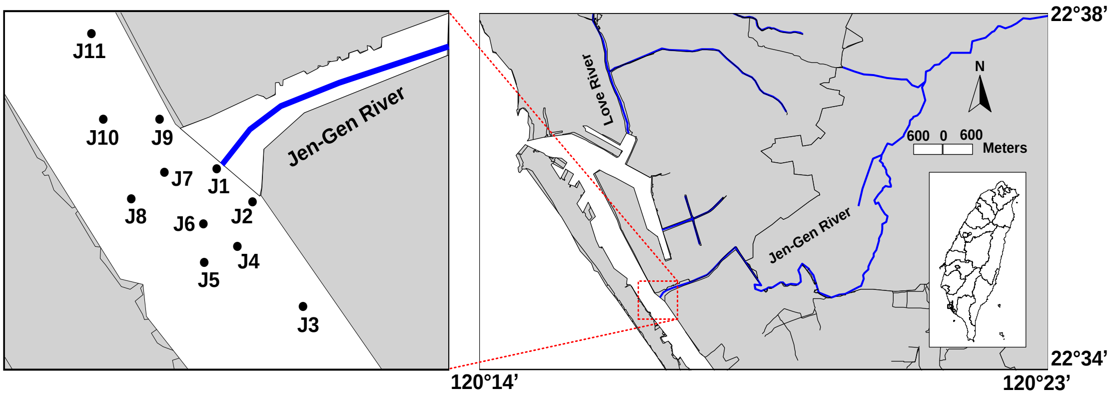

Fig. 1. Map of the study area and sampling locations.

III. Results and Discussion

A. Distribution of Cadmium in Sediments

Contents of Al in the sediment of Jen-Gen River estuary are between 4.11 and 5.71% with an average of 4.78±0.54% (Fig. 2a). All sediment samples collected at Jen-Gen River estuary contain 0.20–4.65 mg/kg of Cd with an average of 1.26±1.23 mg/kg (Fig. 2b). Concentration distributions of Cd in Jen-Gen River estuary sediment shown in Fig. 2(b) reveal that the sediment Cd content is relatively higher in front of the river mouth, and gradually decreases in the direction toward the harbor. Because Jen-Gen River is subject to upstream discharges of treated and un-treated do Fig. 2 Contour map of surface sediments Al and Cd contents in Jen-Gen River Estuary. mestic and industrial wastewaters, the pollutants are transported by river flow and finally accumulate near the river mouth. Some pollutants may drift with sea current to be dispersed into open sea [2]-[6]. Coefficient of the Pearson correlation between the sediment characteristics and Cd content was carried out (Table I). The sediment Cd content are obviously correlated to clay (r = 0.73; $p < 0.05$), but not to OM (r = -0.12; $p > 0.05$), silt (r = 0.22; $p > 0.05$) and sand (r = -0.35; $p > 0.05$) indicating that clay (dia. <2 μm) may be major factors to control the Cd distribution.

B. Enrichment Factor

The enrich factor (*EF*) is a useful tool for differentiating the man-made and natural sources of metal enrichment [2], [3], [6]. This evaluating technique is carried out by normalizing the metal concentration based on geological characteristics of sediment. Aluminum 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 [2], [3], [6]. *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, which excerpted from the data published by Taylor [7]. 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: 1, no enrichment for $EF < 1$; 2, minor for $1 < EF < 3$; 3, moderate for $3 \le EF < 5$; 4, moderately severe for $5 \le EF < 10$; 5, severe for $10 \le EF < 25$; 6, very severe for $25 \le EF < 50$; and 7, extremely severe for $EF \ge 50$. Table II (a) show *EF* values of the sediment Cd for the Jen-Gen River mouth region; the Cd concentration is consistent with the Cd *EF* value for all sampling stations, 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 J6 and J10 are classified as minor enrichment, sites J2, J3 and J5 are classified as moderately severe enrichment, site J9 is classified as moderate enrichment, and the other sites are classified as either severe or very severe enrichment. These results point out that the sediment near the river estuary experiences severe enrichment of Cd that originates from the upstream sources of pollution. Additionally, the average *EF* value of 10.9 obtained in this study is lower than the average *EF* value of 20.3 reported earlier [2] 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 Jen-Gen River flow and dredging the river mouth.

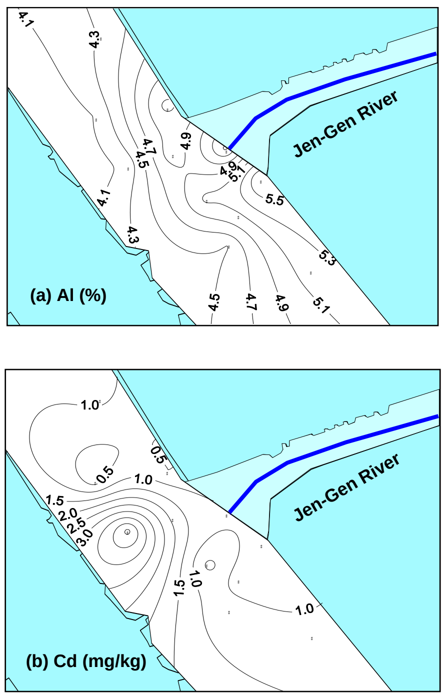

Fig. 2. Contour map of surface sediments Al and Cd contents in Jen-Gen river estuary.

TABLE I: PEARSON CORRELATION COEFFICIENTS AMONG SEDIMENT CHARACTERISTICS AND CD CONCENTRATIONS (N = 10).

	Clay	Silt	Sand	Water content	OM	TG	Al
Silt	0.61[b]						
Sand	-0.71[b]	-0.99[a]					
Water content	0.20	0.61[b]	-0.58				
OM	0.02	0.58	-0.52	0.81[a]			
TG	0.04	0.76[a]	-0.69[b]	0.61[b]	0.66 b		
Al	0.02	0.47	-0.42	0.35	0.16	0.57	
Cd	0.73[b]	0.22	-0.32	-0.06	-0.12	-0.33	-0.26

[a]Correlation is significant at the 0.01 level (2-tailed); [b]Correlation is significant at the 0.05 level (2-tailed).

TABLE II: *EF*, I_{GEO}, PI, AND PERI OF CD FOR EACH STATION STUDIED AT JEN-GEN 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
J1	10.2	5	severe	1.8	2	moderate	5.3	158	higher
J2	8.3	4	moderately severe	1.9	2	moderate	5.8	173	high
J3	7.5	4	moderately severe	1.7	2	moderate	4.8	143	higher
J4	11.8	5	severe	2.3	3	moderately strong	7.3	218	high
J5	5.5	4	moderately severe	1.0	2	moderate	3.0	90	higher
J6	2.7	1	minor	0.2	1	none to medium	1.7	51	moderate
J7	15.2	5	severe	2.6	3	moderately strong	9.3	278	high
J8	46.1	6	very severe	3.9	4	strong	23.3	698	serious
J9	4.0	3	moderate	0.7	1	none to medium	2.5	75	moderate
J10	2.0	1	minor	-0.6	0	none	1.0	30	low
J11	11.0	5	severe	1.9	2	moderate	5.8	173	high
Mean	10.9	5	severe	2.1	3	moderately strong	6.3	189	high

C. 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} values for the metals studied were calculated using the Muller's (1971) expression [8]: $I_{geo} = log_2 (Cn/1.5Bn)$, where Cn is the measured content of element Cd, and Bn 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 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 Muller's [8] geo-accumulation indexes, the accumulation levels with respect to Cd at each station are ranked in Table II (b). Sites J4, J7 and J8 are classified as either moderately strong or strong accumulation, sites J1–3, J5 and J11 are classified as moderate accumulation, and the other sites are classified as either none or none to medium accumulation.

D. 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 [9] can be used to evaluate the potential risk of one metal or combination of multiple metals. The 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 concentration in earth crust of 0.2 mg/kg [7] was taken as the Cd background concentration. The calculated PERI values can be categorized into 5 classes of potential ecological risks [9]: low risk ($PERI < 40$), moderate risk ($40 \leq PERI < 80$), higher risk ($80 \leq PERI < 160$), high risk ($160 \leq PERI < 320$), and serious risk ($PERI \geq 320$). Table II (c) lists the PI value, *PERI* value and risk classification for the Cd contained in the surface sediment samples collected near Jen-Gen River estuary. Sites J6, J9 and J10 are classified as either low or moderate risk, site J8 is classified as serious risk and the other sites are classified as either higher or high risk with respect to Cd pollution. The above evaluation results indicate that the Cd contained in surface sediments at Jen-Gen River mouth has high potential ecological risks.

IV. CONCLUSIONS

The sediment samples collected at Jen-Gen River estuary contain 0.20–4.65 mg/kg of Cd with an average of 1.26±1.23 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 Jen-Gen River mouth sediments were minor to severe enrichment with Cd. Compared to the EF value of 20.3 reported earlier [2]; the degree of Cd enrichment at Jen-Gen River estuary has been obviously reduced. Results of I_{geo} analysis show that the Jen-Gen River estuary sediments were none to strong accumulation with Cd. Results of potential ecological risk evaluation show that the classification of potential ecological risk for the sediment Cd at Jen-Gen River estuary is high risk. The results can provide regulatory valuable information to be referenced for developing future strategies to renovate and manage river mouth and harbor.

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