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Distribution and Accumulation of Mercury in Sediments of Kaohsiung River Mouth, Taiwan

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Abstract

This study was conducted using the data collected in May 2009 to investigate and analyze mercury (Hg) contained in the surface sediments, and to evaluate the accumulation of Hg and the degree of its potential risk. The results show that samples collected at all monitoring stations near the mouth of Kaohsiung River contain 0.15–1.15 mg kg^{-1} of Hg with average of 0.68±0.30 mg kg^{-1}. The spatial distribution of Hg reveals that the Hg concentration is relatively high in the river mouth region, 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. The accumulation factor and potential ecological risk index indicate that the sedimentation at Kaohsiung River mouth has the most serious degree of Hg accumulation and the highest ecological potential risk. Therefore, a strategy for effective controlling and managing Kaohsiung River upstream pollution needs to be immediately implemented in order to improve the sediment quality and alleviate the ecological risk.

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Keywords: mercury; sediment; river mouth; enrichment factor

1. Introduction

The metals generated by anthropogenic activities cause more environmental pollution than naturally occurring metals [1]. After entering a water body, heavy metals will be carried over to sea so that the river mouth and regions along seashore become the ultimate resting place for these metals being transported in the environment. Hence, the river mouth region, harbor and seashore with dense population and industries usually become heavily polluted by toxic metals [2]. Mercury (Hg) is extremely toxic and highly bio-

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accumulative [3-4]; its presence threatens the water ecological environment. Therefore, much research effort has been directed toward the distribution of Hg in water environment. Anthropogenic activities including municipal wastewater discharges, agriculture, mining, incineration, and discharges of industrial wastewater are the major source of Hg pollution [5]. Mercury has low solubility in aqueous solution; it is easily adsorbed on water-borne suspended particles. After a serious of natural processes, the water-borne Hg finally accumulates in the sediment, and the quantity of Hg contained in the sediment reflect the degree of pollution for the water body [6]. Kaohsiung 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 Hg distribution in the surface sediment near Kaohsiung River mouth so that the degree of Hg accumulation and potential ecological risk can be evaluated.

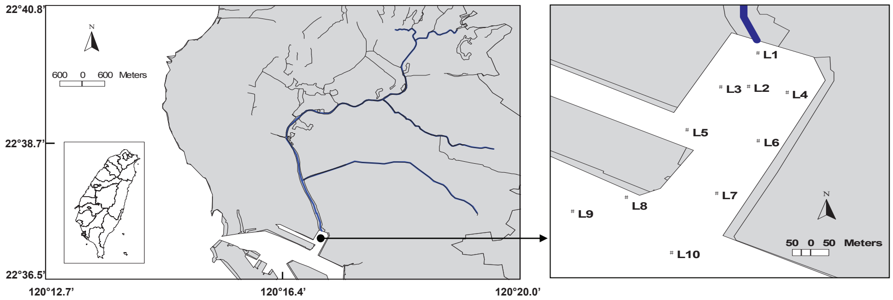

Fig. 1. Map of the study area and sampling locations.

2. Materials and methods

Surface sediment samples were collected at 10 stations near Kaohsiung River mouth (Fig. 1) in May, 2009 with Ekman Dredge Grab aboard a fishing boat. The collected samples were temporarily placed in polyethylene bottles that had been washed with acid; the bottles were stored in a dark ice chest filled with crushed ice. After transported back to the laboratory, a small portion of the sample was subject to direct water content analysis (105°C), and the remaining portion was preserved in -20°C freezer to be analyzed later. Prior to being analyzed, each sample was lightly crushed with a wooden board, and then screened through 1 mm nylon net to remove particles with diameters larger than 1 mm. One portion of the screened portion was subject to particle size analyses using a Coulter LS Particle Size Analyzer. Another portion was washed with ultra-pure water to remove sea salt; the salt-free particles were dried naturally in a dark place, grounded into fine powder with mortar and pestle made of agate, and then analyzed for organic matter (OM), total grease (TG), Hg, and aluminum (Al).

Statistical data analyses include average, standard deviation, maximum and minimum. The linear correlation of Pearson technique was used to analyze the correlation between sediment characteristics and Hg concentration implemented with the SPSS 12.0 software. In this study, the enrichment factor (EF) was applied to evaluate the degree of Hg 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 Hg to aluminum. The average aluminum content in the earth crust was excerpted from the data published by Taylor (1964) [7]. The potential ecological risk index PERI is defined as: $PERI = PI \times T_i$ [8], where PI is the pollution index of Hg (C_i/C_f); T_i is its corresponding coefficient, i.e. 40 for Hg [9]; C_i is the measure concentration of Hg in sediment; C_f is the background concentration of Hg. In this study, the average Hg concentration in the bottom core sediment (80 cm) of 0.085 mg kg^{-1} [10] was taken as the Hg background concentration.

3. Results and discussion

3.1. Characteristics and distribution of mercury in sediments

Table 1 lists the sediment characteristics, mercury contents and enrichment factor in the surface sediments of Kaohsiung river mouth. All sediment samples collected at Kaohsiung River mouth contain 0.15–1.15 mg kg^{-1} of Hg with an average of 0.68±0.30 mg kg^{-1}. Concentration distributions of Hg in Kaohsiung River mouth sediment shown in Fig. 2 reveal that the sediment Hg content is relatively higher near the boundary of the river mouth, and gradually decreases in the direction toward the harbor. Because Kaohsiung River is subject to upstream discharges of un-treated domestic 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 [11].

Coefficient of the Pearson correlation between the sediment characteristics and Hg content were carried out. The sediment Hg content is obviously correlated to water content ($r = 0.69$, $p<0.05$) but not to either OM ($p>0.05$) or particle size ($p>0.05$) indicating that OM and particle size are not major factors to control the Hg distribution [12]. The environmental condition of the river mouth in this study region such as discharges of upstream pollutants, and alternation between fresh water and sea water may be very complicated so that very little correlation between the sediment Hg concentration and other sediment characteristics is observed to exist.

Table 1. Sediment characteristics, mercury contents and enrichment factor in the surface sediments of Kaohsiung river mouth

Station	Clay (%)	Silt (%)	Sand (%)	Water content (%)	OM (%)	TG (mg kg^{-1})	Al (%)	Hg (mg kg^{-1})	EF
L1	10.6	81.4	8.0	64	5.7	5951	4.96	0.35	7
L2	9.0	73.5	17.5	86	7.3	4518	5.80	0.57	10
L3	9.7	87.8	2.5	79	7.5	11739	4.30	0.60	14
L4	11.3	79.5	9.2	101	7.3	5276	5.03	1.10	22
L5	8.8	86.1	5.1	55	4.5	2141	5.05	0.15	3
L6	11.1	79.0	9.9	87	6.2	4260	5.50	0.75	14
L7	7.5	77.0	15.5	83	6.8	3151	4.88	1.15	24
L8	9.5	87.5	3.0	67	4.3	5194	4.93	0.75	16
L9	12.6	80.2	7.2	98	5.9	3163	3.34	0.80	25
L10	12.2	85.9	1.9	94	6.8	7500	5.71	0.60	11
Mean	10.2	81.8	8.0	81.4	6.2	5,289	4.95	0.68	7
SD	1.6	4.8	5.3	15.2	1.1	2,741	0.72	0.30	10

3.2. Assessment of potential ecological risk

The potential ecological risk index (PERI) is applied to evaluate the potential risk associated with the accumulation of Hg in surface sediments. PERI that was proposed by Hakanson (1980) [8] 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: 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 3 lists the PI value, PERI value, and risk classification for the Hg contained in the surface sediment samples collected near Kaohsiung River mouth. Except Station L5 that is classified as moderate risk, all other stations are classified between high risk to serious risk with respect to Hg pollution. The above evaluation results indicate that the Hg contained in surface sediments at Kaohsiung River mouth has high 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.

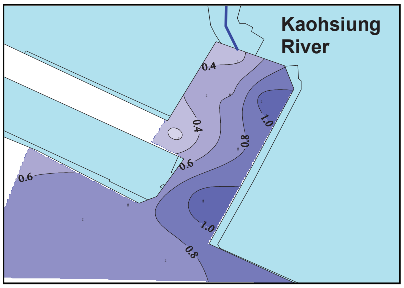

Fig. 2. Distribution of Hg contents (mg kg^{-1}) in surface sediment of Kaohsiung River mouth.

3.3. Enrichment factor

The enrichment factor (EF) is a useful tool for differentiating the man-made and natural sources of metal contamination [13-15]. 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 [11, 16]. 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]: no enrichment for EF <1, minor for EF <3, moderate for EF = 3–5, moderately severe for EF = 5–10, severe for EF = 10–25, very severe for EF = 25–50, and extremely severe for EF >50. Table 1 show EF values of the sediment Hg for the Kaohsiung River mouth region; the Hg concentration is consistent with the Hg EF value for all sampling stations, and all EF values are greater than 1. This indicates that the sediment Hg has enrichment phenomenon with respect to the earth crust and that all Hg originates from man-made sources. Except Station L5 that has moderate enrichment of Hg, all other sampling stations are classified as either moderately severe or severe enrichment. These results point out that the sediment near Kaohsiung River experiences severe accumulation of Hg that originates from the upstream sources of pollution. Additionally, the average EF value of 15±7 obtained in this study is much lower than the average EF value of 76 reported earlier [11] 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 Kaohsiung River flow and dredging the river mouth.

Table 2. Pollution index and potential ecological risk index for Hg in sediments of Kaohsiung River mouth

Station	Pollution index	Potential ecological risk index[a]	Risk level	Station	Pollution index	Potential ecological risk index[a]	Risk level
L1	4	165	High	L6	9	353	Serious
L2	7	267	High	L7	14	541	Serious
L3	7	282	High	L8	9	353	Serious
L4	13	518	Serious	L9	9	376	Serious
L5	2	71	Moderate	L10	7	282	Serious

[a] PERI < 40 indicates low risk, 40 ≤ PERI < 80 is moderate risk, 80 ≤ PERI < 160 is higher risk, 160 ≤ PERI < 320 is high risk, and PERI ≥ 320 is serious risk [8].

4. Conclusions

The surface sediment samples collected at all sampling stations at Kaohsiung River mouth contain 0.15–1.15 mg kg^{-1} of Hg with an average of 0.68±0.30 mg kg^{-1}. The distribution of Hg in surface sediment reveals that the Hg 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 mouth. Results of EF analyses indicate that the degree of EF for the Hg in the sediment at Kaohsiung River mouth has reached serious level (EF = 15). Compared to the EF value of 76 reported earlier [11], the degree of Hg enrichment at Kaohsiung River mouth has been obviously reduced. This may be associated with river renovation and river mouth dredging. Results of potential ecological risk evaluation show that the classification of potential ecological risk for the sediment Hg at Kaohsiung River mouth is between "high risk" to "serious 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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