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SciVerse ScienceDirect
Energy Procedia 16 (2012) 901 – 906
Energy Procedia

2012 International Conference on Future Energy, Environment, and Materials

Copper Contamination in the Sediments of Salt River Mouth, Taiwan

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Abstract

This study was conducted using the data collected at the mouth of Salt River to investigate and analyze copper (Cu) contained in the sediments, and to evaluate the accumulation of Cu and the degree of its potential risk. The results show that samples collected at all monitoring stations near the mouth of Salt River contain 286–895 mg/kg of Cu with average of 501±243 mg/kg. The spatial distribution of Cu reveals that the Cu 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 Salt River mouth has the most serious degree of Cu accumulation and the highest ecological potential risk.

Keywords: copper; sediment; river mouth; enrichment factor

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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]. Copper (Cu) is extremely toxic and highly bio-accumulative [3]-[4]; its presence threatens the water ecological environment. Therefore, much research effort has been directed toward the distribution of Cu in water environment. Anthropogenic activities

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doi:10.1016/j.egypro.2012.01.144

including municipal wastewater discharges, agriculture, mining, incineration, and discharges of industrial wastewater are the major source of Cu pollution [5]. Copper has low solubility in aqueous solution; it is easily adsorbed on water-borne suspended particles. After a series of natural processes, the water-borne Cu finally accumulates in the sediment, and the quantity of Cu contained in the sediment reflect the degree of pollution for the water body [6].

Salt River is approximately 5 km long, and drains a catchment of less than 12 km2. 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 [7]. 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 Cu distribution in the surface sediment near Salt River mouth so that the degree of Cu accumulation and potential ecological risk can be evaluated.

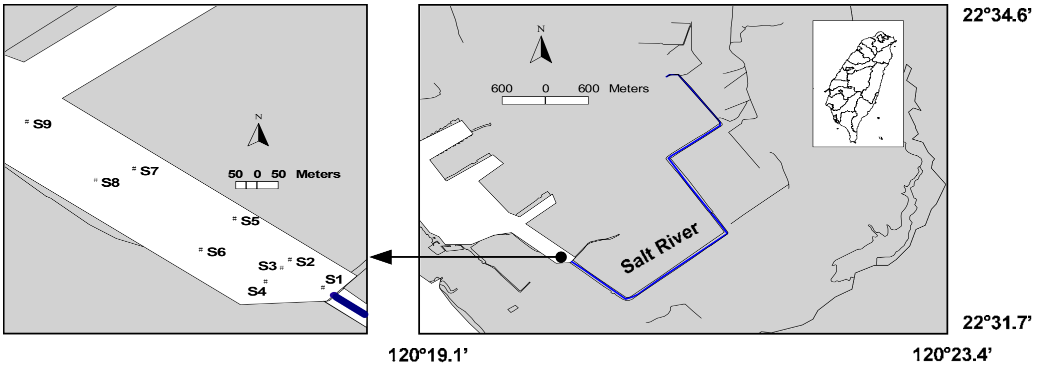

Fig. 1. Map of the study area and sampling locations.

2. Materials and methods

Sediment samples were collected at 9 stations near Salt 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, total grease (TG), Cu, and aluminum (Al). Details of the sediment characteristics (e.g. particle size, water content, OM, TG, and Al) are listed elsewhere [7].

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 Cr concentration implemented with the SPSS 12.0 software. In this study, the enrichment factor (EF) and geo-accumulation index (I_{geo}) were applied to evaluate the degree of Cu 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 Cu to aluminum. The average aluminum content in the earth crust was excerpted from the data published by Taylor (1964) [8]. The I_{geo} is defined as: $I_{geo} = \log_2 (C_n/1.5B_n)$ [9], where C_n is the measured content of Cu, and B_n is the background content of Cu in the average shale. The potential ecological risk index PERI is defined as: $PERI = PI \times T_i$ [10], where PI is the pollution index of Cu (C_i/C_f); T_i is its corresponding coefficient, i.e. 5 for Cu [11]; C_i is the measure concentration of Cu in sediment; C_f is the background concentration of Cu. In this study, the average Cu concentration in the bottom core sediment (80 cm) of 15 mg/kg [12] was taken as the Cu background concentration.

3. Results and discussion

3.1. Distribution of cadmium in sediments

Fig 1 shows the distribution of Cu contents and enrichment factor in the surface sediments of Salt River mouth. All sediment samples collected at Salt River mouth contain 286–895 mg/kg of Cu with an average of 501±243 mg/kg. Concentration distributions of Cu in Salt River mouth sediment shown in Fig. 2 reveal that the sediment Cu content is relatively higher near the river mouth, and gradually decreases in the direction toward the harbor. Because Salt 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].

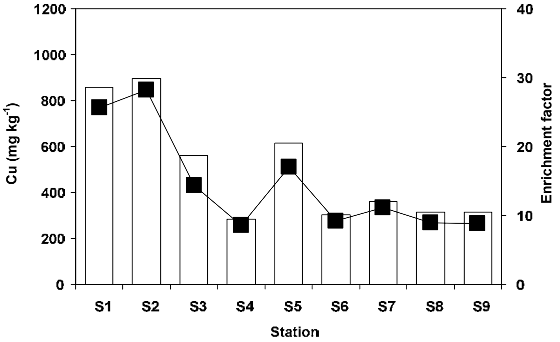

Fig. 2. Distribution of Copper (Cu) contents in surface sediment of Salt River mouth

Coefficient of the Pearson correlation between the sediment characteristics and Cu content was carried out (Table 1). The sediment Cu content is not obviously correlated to either OM or particle size ($p>0.05$) indicating that OM and particle size are not major factors to control the Cu distribution [13]. 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 Cu concentration and other sediment characteristics is observed to exist.

Table 1 Pearson correlation coefficients among sediment characteristics and Cu concentrations (n = 9)

	Clay	Silt	Sand	Water content	OM	TG	Al
Silt	-0.353						
Sand	-0.622	-0.513					
Water content	-0.475	0.011	0.427				
OM	0.123	-0.555	0.356	0.025			
TG	-0.157	0.183	-0.007	0.381	0.174		
Al	0.690[b]	-0.337	-0.349	-0.133	0.251	-0.139	
Cu	-0.308	0.156	0.157	0.148	0.309	0.813[a]	-0.102

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

3.2. Enrichment factor and index of geo-accumulation

The extent of sediment contamination was assessed using the enrich factor (EF) and geo-accumulation index (I_{geo}). EF is a useful tool for differentiating the man-made and natural sources of metal contamination [14-16]. 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 [17-18]. 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 [19]: 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 2 show EF values of the sediment Cu for the Salt River mouth region; the Cu concentration is consistent with the Cu EF value for all sampling stations, and all EF values are greater than 1. This indicates that the sediment Cu has enrichment phenomenon with respect to the earth crust and that all Cu originates from man-made sources. Except Stations S1, and S6 that has very severe enrichment of Cu, all other sampling stations are classified as either moderately severe or severe enrichment. Based on the I_{geo} data and Muller's geo-accumulation indexes, the contamination level with respect to Cu at each station is ranked in Table 2. Based on the above observations, sediments at the Salt River mouth was severe polluted. These results point out that the sediment near Salt River experiences severely accumulation of Cu that originates from the upstream sources of pollution.

Table 2. EF and I_{geo} classes of Cu for each station studied at the Salt River mouth

Station	EF	EF class[a]	I_{geo}	I_{geo} class[b]	Station	EF	EF class[a]	I_{geo}	I_{geo} class[b]
S1	25.6	5	3.4	4	S6	9.3	3	1.9	2
S2	28.2	5	3.4	4	S7	11.2	4	2.1	3
S3	14.3	4	2.8	3	S8	9.0	3	1.9	2
S4	8.5	3	1.8	2	S9	8.8	3	1.9	2
S5	17.0	4	2.9	3	mean	14.7	4	2.5	3

a. 0: EF <1 (no enrichment), 1: EF <3 (minor), 2: EF = 3–5 (moderate), 3: EF = 5–10 (moderately severe), 4: EF = 10–25 (severe), 5: EF = 25–50 (very severe), and 6: EF >50 (extremely severe) [19].

b. 0: I_{geo} <0 (none), 1: I_{geo} = 0–1 (none to medium), 2: I_{geo} = 1–2 (moderate), 3: I_{geo} = 2–3 (moderately to strong), 4: I_{geo} = 3–4 (strongly polluted), 5: I_{geo} = 4–5 (strong to very strong), and 6: I_{geo} >5 (very strong) [9]

3.3. Assessment of potential ecological risk

The potential ecological risk index (PERI) is applied to evaluate the potential risk associated with the accumulation of Cu in surface sediments. PERI that was proposed by Hakanson (1980) [10] 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 4 lists the PI value, PERI value, and risk classification for the Cu contained in the surface sediment samples collected near Salt River mouth. All stations are classified between higher to high risk with respect to Cu pollution. The above evaluation results indicate that the Cu contained in surface sediments at Salt 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.

Table 3 Pollution index and potential ecological risk index of Cu in sediments of Salt River mouth

Station	PI	PERI[a]	Risk level	Station	PI	PERI[a]	Risk level
S1	58	291	high	S6	21	103	higher
S2	61	304	high	S7	24	122	higher
S3	38	191	high	S8	21	107	higher
S4	19	97	higher	S9	22	108	higher
S5	42	209	high	mean	34	170	high

[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 [10].

4. Conclusions

The sediment samples collected at all sampling stations at Salt River mouth contain 286–895 mg/kg of Cu with an average of 501±243 mg/kg. The distribution of Cu in sediment reveals that the Cu 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 and I_{geo} analyses indicate that the Salt River mouth sediments were moderately contaminated with Cu. 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 Cu at Salt River mouth 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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