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# Evaluation of Zinc Contamination in the Sediments of Salt River Mouth, Taiwan

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**Keywords:** Accumulation, Enrichment, Sediment, Sediment Quality Guidelines (SQGs), Zinc.

**Abstract** The distribution, enrichment, and accumulation of Zinc (Zn) in the surface sediments of Salt River mouth, Taiwan, were studied. Results show that samples collected from nine stations near the mouth of Salt River contain 440–1,820 mg/kg of Zn with average of 951±811 mg/kg. The spatial distribution of Zn reveals 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. Enrichment factor analysis indicates that the sediments of Salt River mouth were moderately severe enrichment with Zn. Geo-accumulation index analysis indicates that the sediments of Salt River mouth were strongly accumulated with Zn. Base on the comparison with sediment quality guidelines (SQGs), the concentrations of Zn in the sediments of Salt River mouth may cause acute biological damage.

## 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 [2-3]. Zn has low solubility in aqueous solution; it is easily adsorbed on water-borne suspended particles. After a series of natural processes, the water-borne Zn finally accumulates in the sediment, and the quantity of Zn contained in the sediment reflect the degree of pollution for the water body [3]. The Salt River flows through the Linhai Industrial Park and China Steel Plant (the largest steel plant in Taiwan) and is finally discharged into Kaohsiung Harbor (Fig.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 mouth to threaten the water environmental ecological system seriously. The objective of this study is to investigate the Zn distribution in the surface sediment near Salt River mouth so that the degree of Zn accumulation and potential ecological risk can be evaluated.

## Materials and Methods

Surface sediment samples were collected at nine stations near Salt River mouth (Fig. 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 [3]. The Al and Zn contents were determined using a flame atomic absorption spectrophotometry (Hitachi Z-6100).

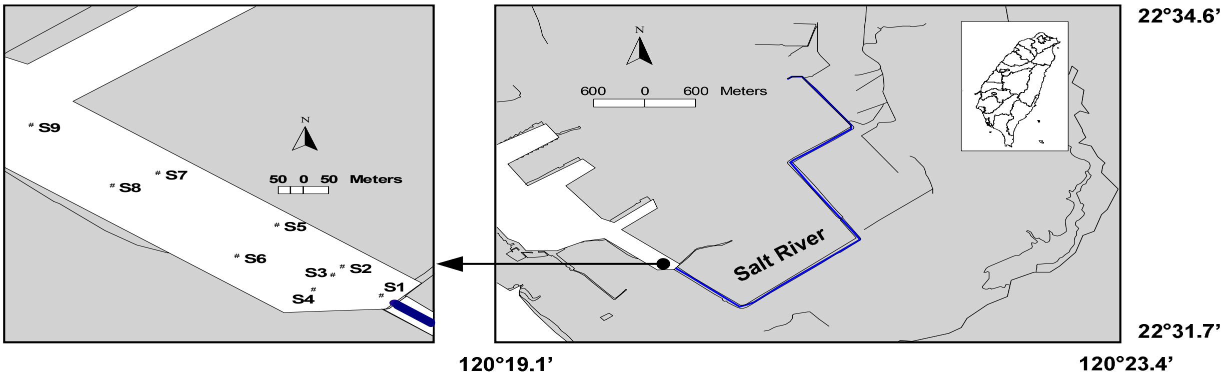


Fig. 1 Map of the study area and sampling locations.

## Results and Discussion

**Distribution of Zn in Sediments.** Contents of Al in the sediment of Love River mouth are between 3.34 and 5.8% with an average of 4.95±0.72%. All sediment samples collected at Salt River mouth contain 440–1,820 mg/kg of Zn with an average of 951±511 mg/kg. Concentration distributions of Zn in Salt River mouth sediment shown in Fig. 2 reveal that the sediment Zn 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 [4-6]. Coefficient of the Pearson correlation between the sediment characteristics and Zn content is shown in Table 1. The sediment Zn content is not obviously correlated to either OM or particle size ($p>0.05$) indicating that OM and particle size may not major factors to control the Zn distribution [2]. 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 Zn concentration and other sediment characteristics is observed to exist.

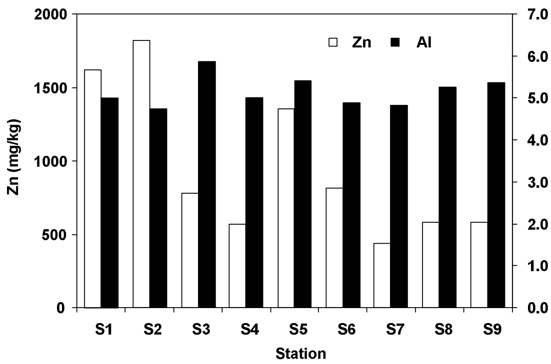


Fig. 2 Distribution of Al and Zn contents in surface sediments of Salt River mouth.

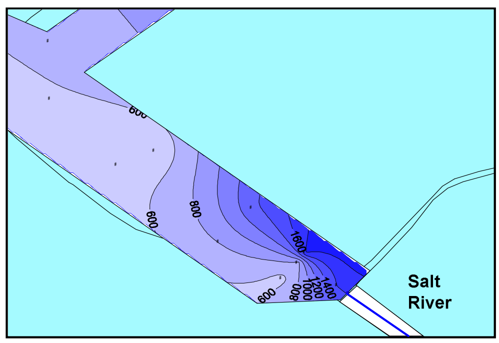


Fig. 3 Contour map of surface sediments Zn contents in Salt River mouth.

**Enrichment Factor.** The enrich factor (EF) is a useful tool for differentiating the man-made and natural sources of metal enrichment [2-3]. 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]. EF is defined as: $EF = (X/Al)_{sediment}/(X/Al)_{crust}$, where $(X/Al)$ is the ratio of Zn to Al. The average Zn and Al content in the earth crust were 70 mg/kg and 8.23%, that excerpted from the data published by Taylor (1964) [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 [2]: 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 2(a) show EF values of the sediment Zn for the Salt River mouth region; the Zn concentration is consistent with the Zn EF value for all sampling stations, and all EF values are greater than 1. This indicates that the sediment Zn has enrichment phenomenon with respect to the earth crust and that all Zn originates from man-made sources. Stations S1, S2, and S5 are classified as severe enrichment, and the other Stations are classified as moderately severe enrichment. These results point out that the sediment near the boundary of the river mouth experiences severe enrichment of Zn that originates from the upstream sources of pollution. Additionally, the average EF value of 22 obtained in this study is higher than the average EF value of 9.1 reported earlier [2] indicating that the upstream pollution has been continued to increase so that the accumulation of pollutants in sediments is more serious than that during earlier years.

Table 1 Correlation coefficients among sediment characteristics and zinc concentrations (n = 9)

| | Clay | Silt | Sand | Water content | OM | Total Greaes | 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 | | | |
| Total Greaes | -0.157 | 0.183 | -0.007 | 0.381 | 0.174 | | |
| Al | 0.690[b] | -0.337 | -0.349 | -0.133 | 0.251 | -0.139 | |
| Zn | -0.495 | 0.267 | 0.235 | 0.434 | 0.227 | 0.862[a] | -0.234 |

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

Table 2 EF, $I_{geo}$, PI, and PERI of Zn for each station studied at Salt River mouth

| Station | (a) Enrichment factor[a] | | | (b) Geo-accumulation index[b] | | |
|---|---|---|---|---|---|---|
| | EF value | EF class | EF level | $I_{geo}$ value | $I_{geo}$ class | $I_{geo}$ level |
| S1 | 38 | 5 | severe | 3.9 | 4 | strong |
| S2 | 45 | 5 | severe | 4.1 | 5 | strong to very strong |
| S3 | 16 | 4 | moderately severe | 2.9 | 3 | moderate to strong |
| S4 | 13 | 4 | moderately severe | 2.4 | 3 | moderate to strong |
| S5 | 30 | 5 | severe | 3.7 | 4 | strong |
| S6 | 20 | 4 | moderately severe | 3.0 | 4 | strong |
| S7 | 11 | 4 | moderately severe | 2.1 | 3 | moderate to strong |
| S8 | 13 | 4 | moderately severe | 2.5 | 3 | moderate to strong |
| S9 | 13 | 4 | moderately severe | 2.5 | 3 | moderate to strong |
| Mean | 22 | 4 | moderately severe | 3.0 | 4 | strong |

**Geo-accumulation Index.** Similar to metal enrichment factor, index of geo-accumulation (Igeo) can be used as a reference to estimate the extent of metal accumulation. The Igeo values for the metals studied were calculated using the Muller's (1979) expression [8]: $I_{geo} = log_2 (C_n/1.5B_n)$, where $C_n$ is the measured content of element Zn, and $B_n$ is the background content of Zn 70 mg/kg [7], in the average shale. 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 (1979) [8] geo-accumulation indexes, the accumulation levels with respect to Zn at each station are ranked in Table 2(b). Stations S1, S2, S5, and S6 are classified as either strong or strong to very strong accumulation, and the other Stations are classified as moderate to strong accumulation.

**Comparison with sediment quality guidelines.** Several numerical sediment quality guidelines have been developed for assessing the contamination levels and the biological significance of chemical pollutants recently [9]. One of the widely used sediment toxicity screening guideline of the US

National Oceanic and Atmospheric Administration provides two target values to estimate potential biological effects: effects range low (ERL) and effect range median (ERM) [9]. The guideline was developed by comparing various sediment toxicity responses of marine organisms or communities with observed metals concentrations in sediments. These two values delineate three concentration ranges for each particular chemical. When the concentration is below the ERL, it indicates that the biological effect is rare. If concentration equals to or greater than the ERL but below the ERM, it indicates that a biological effect would occur occasionally. Concentrations at or above the ERM indicate that a negative biological effect would frequently occur. Fig. 4 shows the measured concentrations of Zn in comparison with the ERM and ERL values. All the 9 sediment samples are exceeding ERM for Zn indicates that biological effects would frequently occur.

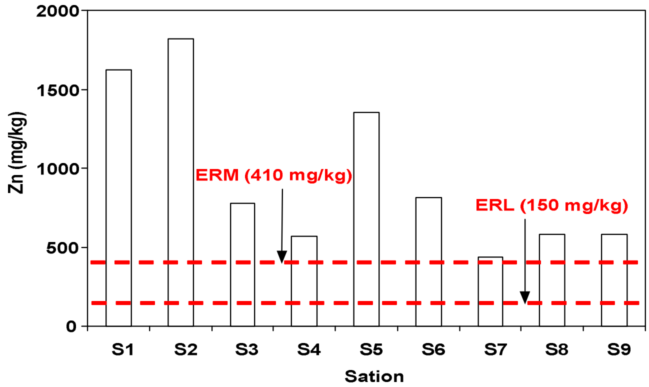


Fig. 4 Distribution of Zn contents in surface sediments of Salt River mouth. Lines mark the levels or risk considered. ERL (Effects Range Low) and ERM (Effects Range Median)

## Conclusions

The sediment samples collected at all sampling stations at Salt River mouth contain 440–1,820 mg/kg of Zn with an average of 951±551 mg/kg. The distribution of Zn in sediment reveals that the Zn 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 analysis indicate that the Salt River mouth sediments was moderately severe enrichment with Zn. Results of $I_{geo}$ analysis indicate that the Salt River mouth sediments was strongly accumulated with Zn. Base on the comparison with SQGs, the concentrations of Zn in Salt River mouth sediments may cause acute biological damage. 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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