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# Assessment of heavy metals contamination in soil profiles of roadside *Suaeda salsa* wetlands in a Chinese delta

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ABSTRACT

Five sampling sites (Sites A, B, C, D and E) were selected along a 250 m sampling zone covered by *Suaeda salsa*, which is perpendicular to a road, in the Yellow River Delta of China. Soil samples were collected to a depth of 40cm in these five sampling sites to investigate the profile distributions and toxic risks of heavy metals. Concentrations of heavy metals (As, Cd, Cr, Cu, Ni, Pb and Zn) were determined using inductively coupled plasma atomic absorption spectrometry (ICP-AAS). The results showed that in each sampling site, Cd, Cu, Pb and Zn have approximately constant concentrations along soil profiles and did not show high contamination compared with the values of probable effect levels (PELs). All soils exhibited As and Ni contamination at all sampling sites compared with other heavy metals. The index of geo-accumulation ($I_{geo}$) values for As in the 20–30 cm soil layer at Site B was grouped into Class IV($2 < I_{geo} \leq 3$), indicating that the soil was moderately to strongly contaminated. Forty percent of $I_{geo}$ values of Cd for all soil samples were grouped into Class IV($2 < I_{geo} \leq 3$) and 75% samples of Site C showed moderately to strongly contaminated level. The Enrichment factor (EF) values of As at Sites B, C, D and E reached significant enrichment level and EF values of Cd at five sampling sites all reached significant enrichment level. The sum of toxic units ($\sum$TUs) values for surface soils of Sites B and C beyond 4 indicated that Sites B and C have severer toxicity compared with other three sampling sites. As and Ni should be paid more attention to avoid potential ecotoxicity due to their high contribution ratios to the $\sum$TUs in *Suaeda salsa* wetlands. Correlation analysis (CA) and principal components analysis (PCA) revealed that Cr, Cu, Ni, Pb and Zn might derive from the common sources, Cd might originate from another, while As might have more complex sources in this study area.



## 1. Introduction

Located in zones between land and ocean, coastal wetlands are a multifunctional and complex ecosystem with special ecological values and potential resources. However, the rapid development of industry and agriculture around coastal area make the ecosystems more easily destructed. As a result of the physico-chemical processes such as adsorption, ligand exchange and sedimentation, wetland soils act as a source, sink, and transfer for heavy metals (Lau and Chu, 2000; Reddy and DeLaune, 2008). Heavy metals pollution is one of the most typical contaminations caused by anthropogenic activities, because heavy metals can be easily bio-accumulated through food chains and cause heath risks and eco-toxicity even at low levels in the environment (Pejman et al., 2015).

The Yellow River Delta (YRD) is one of the most active regions of land-ocean interactions (Lu et al., 2014). It is estimated that approximately $1.05 \times 10^7$ t of sand and soil per year are carried and deposited in the YRD (Xu et al., 2002). The variation in hydrological conditions was observed in the YRD due to the implementation of flow-sediment regulation (Bai et al., 2012). The active hydrological fluctuations in the YRD make the physico-chemical processes of coastal region more complex (Xu et al., 2002; Lu et al., 2014; Zhou et al., 2015). Additionally, the YRD is under great pressure of environmental degradation caused by aquaculture, petrol oil industries, agriculture, road and harbor construction (Bai et al., 2011; 2012). There was an increasing tendency of heavy metals contamination in the YRD during the last decade caused by sustained and intensive human activities (Nie et al., 2010; Bai et al., 2012). Some

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studies on heavy metals contamination have been performed in this region, but little information is available about the profile distributions of heavy metals in *Suaeda salsa* wetland soils affected by road transportation in the YRD.

Therefore, the primary objectives of this study were: (1) to investigate the profiles distribution of heavy metals (e.g., Cd, Cr, Cu, Ni, Pb and Zn) in *Suaeda salsa* wetland soils perpendicular to a road in the YRD, China; (2) to evaluate the contamination levels based on the index of geo-accumulation ($I_{geo}$) and the enrichment factor (EF) as well as toxic risks using toxic units (TUs); and (3) to identify the possible sources of heavy metals using correlation analysis (CA) and principal components analysis (PCA).

## 2. Materials and methods

### 2.1. Study area

This study was conducted in the Yellow River Delta (37°10′ to 38°40′N and 118°30′ to120°10′E), Shandong province, China. It has a warm-temperate and continental monsoon climate, with annual mean precipitation of 640 mm and annual mean evaporation of 1962 mm. The annual mean air temperature is 11.9 °C, with 196 frostless days (Bai et al., 2015). Intrazonal tidal soil and salt soil are the dominant soil types in the study area (Zhang et al., 2013). The dominant vegetation comprises *Phragmites australis*, *Suaeda salsa*, *Tamarix chinensis*, *Imperata cylindrica* and *Salix metsudana* (Zhang et al., 2016).

### 2.2. Sample collection and analysis

Five sampling sites (Sites A, B, C, D and E) were selected along a 250 m sampling zone covered by *Suaeda salsa*, which was perpendicular to a road (The distances from Sites A, B, C, D and E to the road are 250 m, 200 m, 150 m, 100 m and 50 m, respectively) in the YRD. The top 40 cm soils (sectioned into 0–10 cm, 10–20 cm, 20–30 cm and 30–40 cm) were collected with three replicates, and three replicates of each soil layer were mixed uniformly into one composite sample in the same soil profile and then placed in polyethylene bags and brought to the laboratory. All soil samples were air-dried at room temperature for 3 weeks and sieved through a 2-mm nylon sieve to remove coarse debris and then ground using a pestle and mortar until all particles could pass through a 0.149-mmnylon sieve for the determination of soil chemical properties.

The soil samples were digested with an $HClO_4$-$HNO_3$-HF mixture in Teflon tubes to determine the concentations of total sulfur (TS), total phosphorous (TP), Al, As, Cd, Cr, Cu, Ni, Pb and Zn. The digested sample solutions were analyzed by inductively coupled plasma atomic emission spectrometry (ICP-AES). Quality assurance and quality control were assessed with duplicates, method blanks and standard reference materials (GBW07401) from the Chinese Academy of Measurement Sciences with each batch of samples (1 blank and 1 standard for each 10 samples). The recoveries of samples spiked with standards ranged from 95% to 105%. Soil organic matter (SOM) was measured using dichromate oxidation (Page et al., 1982). Soil pH was measured in 1:5 soil/water (m/v) suspensions with a Hach pH meter (Hach company, Loveland, CO, USA).

### 2.3. Contamination and ecotoxic risk assessment

In this study, the index of geoaccumulation ($I_{geo}$) (Müller, 1979) was used to measure the contamination levels of heavy metals in wetland soils:

$$I_{geo} = \log_2 \frac{C_n}{1.5\,B_n}$$

where $C_n$ is the measured concentration of the element and $B_n$ is the geochemical background concentration of this element. The geoaccumulation values were classified as uncontaminated ($I_{geo} \le 0$), uncontaminated to moderately contaminated ($0 < I_{geo} \le 1$), moderately contaminated ($1 < I_{geo} \le 2$), moderately to strongly contaminated ($2 < I_{geo} \le 3$), strongly contaminated ($3 < I_{geo} \le 4$), strongly to extremely contaminated ($4 < I_{geo} \le 5$), and extremely contaminated ($I_{geo} > 5$). In this study, the reference background values were obtained from the environmental background concentrations of heavy metals in the Yellow River Delta (CNEMC, 1990, Table 1).

Enrichment factor (EF) was used to evaluate the probable exogenous input to selected sample metals. EF was defined as $EF = (M/Al)_{sample}/(M/Al)_{background}$, where M and $M_{background}$ are the determined values of target elements in the sampled soils and the background levels of them, respectively. Al is the normalizing element due to its conservation here (Xiao et al., 2012; Bai et al., 2014). The EF were classified into five classes as follows: (1) EF < 2, minimal enrichment; (2) EF = 2–5, moderate enrichment; (3) EF = 5–20, significant enrichment; (4) EF = 20–40, very high enrichment; and (5) EF > 40, extremely high enrichment (Brady, 1984). Background values of heavy metals were from the China National Environmental Monitoring Center (CNEMC, 1990, Table 1).

To assess the ecotoxicity of heavy metals, the toxic unit (TU) was used to compare the relative impact of various metals in different sites, which is defined as the ratio of the measured concentration to probable effect level (PEL) (Pedersen et al., 1998). The PEL represents the concentration above which adverse effects are expected to occur, and the PEL values for estuarine ecosystem was used in this study (MacDonald et al., 2000, Table 1).

### 2.4. Statistical analysis

Pearson correlation analysis and principle component analysis were carried out using SPSS 17.0 software package to identify the relationships among different metals. The relationships between heavy metals and selected soil properties were also examined by correlation analysis. Differences were considered to be significantly if $P < 0.05$.

## 3. Results and discussion

### 3.1. Heavy metals distribution in soil profiles

The vertical distributions of heavy metals along soil profiles at

**Table 1**
Reference concentrations of heavy metals.

| | Al (mg/kg) | As (mg/kg) | Cd (mg/kg) | Cr (mg/kg) | Cu (mg/kg) | Ni (mg/kg) | Pb (mg/kg) | Zn (mg/kg) |
|---|---|---|---|---|---|---|---|---|
| TEL[a] | – | 7.2 | 0.68 | 52.3 | 18.7 | 15.9 | 30.2 | 124.0 |
| PEL[a] | – | 42.6 | 4.2 | 160.4 | 108.2 | 42.8 | 112.2 | 271.0 |
| Background value[b] | 62700 | 10.7 | 0.095 | 59 | 21.1 | 27.6 | 21.6 | 64.5 |

[a] TEL: threshold effect level; PEL: probable effect level; (Long and Mac Donald, 1998).
[b] Background values in the Yellow River Delta (CNEMC, 1990).