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Effects of freshwater input on trace element pollution in salt marsh soils of a typical coastal estuary, China

Junhong Bai [a,b,*], Qingqing Zhao [a], Qiongqiong Lu [a], Junjing Wang [a], K. Ramesh Reddy [b]

[a] State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, 19 Xinjiekouwai Street, Beiijng 100875, PR China
[b] Soil and Water Science Department, University of Florida, 2181 McCarty Hall A, Gainesville, FL 32611, USA

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SUMMARY

Freshwater input is an important pathway for the restoration of degraded coastal wetlands, however, little information is available on the negative effects of freshwater inputs on salt marsh soils in restored wetlands. Soil profile samples to a depth of 70 cm were collected in both degraded wetland (DW) and freshwater restored wetland (RW) in the Yellow River Delta of China to analyze the trace element pollution effects of freshwater input on coastal wetland soils. Heavy metals (i.e. Cd, Cr, Cu, Ni, Pb and Zn) and arsenic (As) concentrations were determined using the inductively coupled plasma atomic absorption spectrometry to investigate their distributions, sources and ecotoxicity in marsh soils from both wetlands. Our results showed that these trace elements had moderate spatial variability in both DW and RW soils. The concentrations of As, Cr, Pb and Cd in all soil layers were generally higher in RW soils than those in DW soils ($p < 0.05$), whereas the concentrations of Zn and Cu were higher in DW soils. Heavy metals had similar source in both wetlands, however, As and Zn in DW or As, Zn and Ni in RW might have another similar origin. The enrichment factor (EF) values for Cu, Ni and Pb in both wetlands indicated minimal enrichment levels, whereas both As and Cd were significantly enriched with EF values 3 or 6 times greater than 1.5, implying a significant natural or anthropogenic origin. As and Ni exceeded the effect range low (ERL) and threshold effect level (TEL) in both wetlands, even As exceeded the probable effect level (PEL) in RW soils. Cr, Cu and Cd were grouped into TELs-PELs, moreover, Cr concentrations in RW soils exceeded the ERL. However, both Pb and Zn concentrations were below the TELs in both wetlands. Generally, The toxic unit in more than 85% of DW or RW soil samples showed low toxicity with higher contribution of As and Ni. It is necessary to monitor and control trace elements in the freshwater supplied to restored wetlands in coastal wetland restoration projects.

1. Introduction

Wetland drainage or water shortage can lead to serious wetland degradation (Bai et al., 2013), as alterations of hydrology have important impacts on plant communities and the soil biogeochemistry of wetland ecosystems (Mitsch and Gosselink, 2007; Reddy and DeLaune, 2008). In addition to anthropogenic activities, seawater intrusion and freshwater shortage have become great threats to coastal marsh wetlands. Over the past few decades, coastal wetlands are suffering worldwide losses at an average rate of 0.5–1.5% per year (USGS, 1997). Therefore, most restoration projects in coastal wetlands have been practiced to inhibit further wetland degradation, of which high priority has been given to hydrological restoration (Perillo et al., 2010). Freshwater input is considered to be an important pathway to restore degraded coastal wetlands (Wang et al., 2011). Moreover, wetland vegetation, water tables, soil organic matter, and salinity have recently been given considerably more attention in coastal wetland restoration projects (Mitsch and Wang, 2000; Perillo et al., 2010; Wang et al., 2011). However, little information is available on the negative effects (e.g., trace element pollution) of freshwater input on marsh soils in restored wetlands (Bai et al., 2012).

The Yellow River Delta is one of the largest deltas in China, and the large sediment load of the Yellow River makes its delta one of the richest sediment supplies in the world. Thus, water and sand sedimentation from the Yellow River forms an important base for the extension and development of the Yellow River Delta (Huang et al., 2005; Yu et al., 2011) and plays an important role in the formation and maintenance of the coastal estuary wetlands

* Corresponding author at: State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, 19 Xinjiekouwai Street, Beiijng 100875, PR China. Tel.: +86 010 5880 2029; fax: +86 010 5880 0397.

E-mail address: junhongbai@163.com (J. Bai).

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(Li et al., 2009). Coastal wetlands such as reed marshes, meadows, and tidal wetlands decreased by 17%, 37% and 38%, respectively, from 1986 to 2001 due to lower runoff and sediment discharge (Li et al., 2009). A 10,000 hm^2 restoration area project was established in 2002 in which freshwater from the Yellow River is brought to the resorted wetland in the wet season to resist saltwater intrusion, thus increasing the self-regulation capacity of the wetland ecosystem (Cui et al., 2009b); the water and sediment regulation of the upstream Xiaoliangdi hydrological station has been enforced from June to July every year since 2002 (Bai et al., 2012). Most studies have focused on wetland biodiversity (Cui et al., 2009a), wetland landscape changes (Li et al., 2009), wetland ecological water requirements (Cui et al., 2009b) and soil carbon storage (Wang et al., 2011) in the restored wetlands. However, the effects of freshwater restoration on soil trace element pollution risks in restored wetlands are still unknown.

The primary objectives of this study were (1) to investigate trace element concentrations in marsh soils in a restored wetland (RW) as affected by a three-year freshwater input and in the degraded wetland (DW) of the Yellow River Delta; (2) to identify the pollution sources of these trace elements in both wetlands; and (3) to assess the ecotoxicity of trace elements in both wetlands using sediment quality guidelines (SQGs), enrichment factor (EF, the ratio of the targeted metal concentration in soil samples normalized by Al to the normalized background concentration), and toxic unit (TU, the ratio of the determined concentration to PEL value).

2. Materials and methods

2.1. Study area

The study area is located in the Yellow River Delta (37°35′–38°12′N and 118°33′–119°20′E, Fig. 1). It has a warm-temperate and continental monsoon climate, with annual precipitation of 640 mm and annual mean evaporation of 1962 mm. The annual mean air temperature is 11.9 °C, with 196 frostless days. The soil is typical Fluvisols developed on the loess material of the Quaternary period, which was carried by water from the Loess Plateau (Zhang and Hu, 2007; Yu et al., 2011). The restoration project was implemented in June of 2002. The general objective of the restoration project was to improve the hydrological processes and soil conditions in order to provide suitable habitats for freshwater vegetation and water birds because salinization had constituted the primary threat to the freshwater wetland (Cui et al., 2009a). A 9.0-m long, 3.4-m wide and 1.5-m high dyke was constructed to prevent seawater from entering the restored wetland (Wang et al., 2011). Freshwater was pumped into the restored wetland through the channels during the water and sediment regulation from June to July. After three years since the implementation of the restoration project, the ecological conditions have obviously been improved in the restored wetland, with higher SOM, higher biodiversity and lower salinity (with an average Cl concentration of 0.36 g/kg) (Tang, 2006). *Phragmites australis* becomes the dominant plant species in the restored wetland with higher plant productivity. The water level fluctuated up to 1.1 m among all wetlands during the freshwater input, while little water was present in the degraded wetlands (Wang et al., 2011). The degraded wetlands exhibited larger areas of bare land, higher salinity (with an average Cl concentration of 1.75 g/kg) and much lower biodiversity due to the freshwater shortage and seawater intrusion; there was even obvious salt grain in the surface soils (Tang, 2006). The degraded wetlands were not affected by the freshwater restoration project due to the high dyke (Wang et al., 2011).

2.2. Soil collection and analysis

Eight sampling plots were randomly selected in the degraded and restored wetlands in early June of 2005. Soil profiles with three replicates were stratified with four different depths (i.e., 0–10 cm, 10–20 cm, 20–40 cm, and 40–70 cm) at each sampling plot, and the same layers were mixed for a composite sample. In total, 64 soil samples were obtained. All soil samples were placed in polyethylene bags and brought to the laboratory and then air dried at room temperature for three weeks. All of the air-dried soil samples were sieved through a 2-mm nylon sieve to remove coarse debris and stones, and then ground with a pestle and mortar until all particles passed a 0.149-mm nylon sieve for the determination of soil chemical properties.

Soil samples were digested with an $HClO_4$–HNO_3–HF mixture in Teflon tubes to determine the total concentrations of S, P, Al, As, Cd, Cr, Cu, Ni, Pb, and Zn. The digested solutions of the samples were analyzed using the inductively coupled plasma atomic absorption spectrometry (ICP–AAS). Quality assurance and quality control were assessed using 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 106%. Soil organic matter (SOM) was determined using the method of Walkley and Black (1934). Soil pH (H_2O) and conductivity (EC) were measured

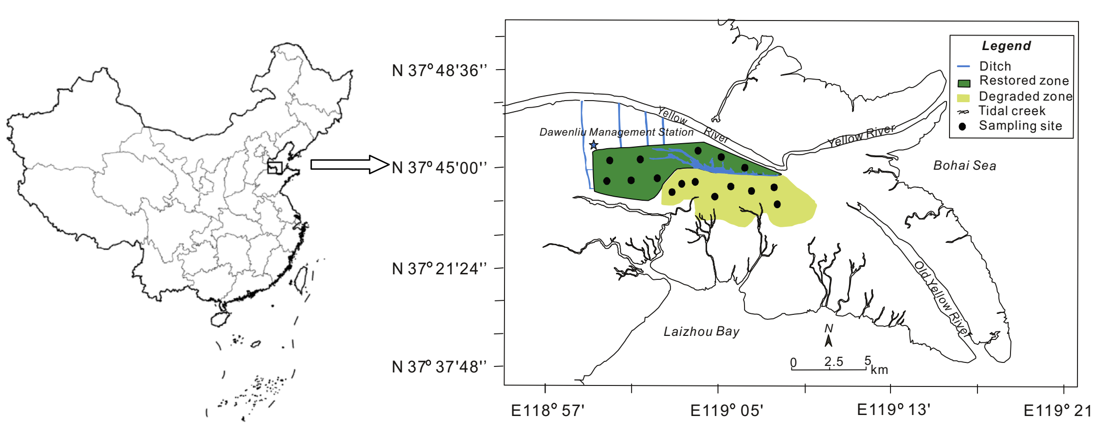

Fig. 1. Location map of sampling sites in the Yellow River Delta. The green area denotes restored wetland; The brown area denotes degraded wetland. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)