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Spatial distribution of dissolved cadmium in the Jiulong river–estuary system: Relevance of anthropogenic perturbation

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ABSTRACT

This study first examined the spatial distribution of dissolved cadmium (Cd) along with other hydrochemical parameters in a large subtropical river estuary system (the Jiulong River–Estuary, China) between 2008 and 2010, aiming to evaluate the impacts of the recently increasing anthropogenic perturbation in natural waters. The results showed that dissolved Cd was variable in the watershed with sporadically high concentrations (>0.6 nmol L^{-1}). The significantly positive correlation of dissolved Cd with phosphate in the watershed (May 2008: dissolved Cd=0.22*P+0.0062, $r=0.64$, $p<0.05$) indicated that dissolved Cd levels have been elevated along with P by the increasing agricultural discharges and/or sewage effluents.

The estuary was characterized with decreased levels of dissolved Cd in the highly turbid upper part (salinity: <5; dissolved Cd: <0.1 nmol L^{-1}; Total Suspended Matter: 100–300 mg/L), and a mid-salinity maximum of dissolved Cd in the middle part, which were higher in Summer high river discharge period (0.40-0.54 nmol L^{-1}) than in Fall low river discharge period (0.25–0.35 nmol L^{-1}). Dissolved Cd generally decreased outwards in the lower estuary and nearby coastal waters as mixed with the low Cd-content seawater offshore (dissolved Cd= −0.025*Salinity+0.96, $r=0.60$, $p<0.05$). In particular, an enhancement of dissolved Cd (by ∼0.2 nmol L^{-1}) was observed in the lower estuary and estuarine plume zone as a result of sewage discharges nearby and/or Cd-enriched submarine groundwater discharges. Summarily, our exemplary study provides clear evidence that China's natural waters are currently subject to local perturbation due to the recently increasing anthropogenic activities.

1. Introduction

Dissolved cadmium (Cd) accounts for more than 90% of the total in aquatic systems (e.g., Kraepiel et al., 1997; Audry et al., 2007), and mainly originates from the chemical weathering of minerals (Pfeifer et al., 2002; Ni et al., 2009; Dai and Martin, 1995). Alternatively, Cd could be released from anthropogenic sources including industrial processing of ores and metals (Garrett, 2000) and agricultural phosphate fertilizers (Garrett, 2000; Cupit et al., 2002; Meeûs et al., 2002).

In urban waters, Cd might be directly discharged from industrial and municipal sewages (Garrett, 2000), leaches from garbage and soil waste dumps, or contaminated soils and sediments (Garrabrants and Kosson, 2000; Zwolsman et al., 1997; Audry et al., 2007), and animal and human excretions which contain heavy metals (Honda et al., 2003). Therefore, Cd contamination commonly occurred in ambient environments worldwide including Europe (Hutton 1983; Jones et al., 1987), United States (e.g., Jouanneau et al., 1993; Flegal et al., 1991; Laslett and Balls, 1995), and Australia (Williams and David, 1973).

In South China, mining activities and agricultural activities have led to a wide existence of Cd contamination in soils and sediments (Liao et al., 2005). There are already few investigations of dissolved Cd in China's rivers and estuaries including the Jiulong River estuary (Li et al., 1987; Gao and Zou, 1996), the Pearl River estuary (Wang et al., 2012), the Yangtze River (e.g., Zhang, 2002), the Pearl River (Li et al., 2007), and the waters of Hong Kong (Chan et al., 1974). These studies focused on either sediments or few measurements of dissolved Cd in natural waters, and there is still little information available regarding any large system including a watershed, its estuary and adjacent coastal waters.

This study first investigated the spatial distribution of dissolved Cd in the whole river–estuary system (the Jiulong River–Estuary system, China). The objective of the study is to identify anthropogenic sources of dissolved Cd, and evaluate the responses of dissolved Cd to the currently increasing anthropogenic activities in

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China. Our results showed that slight perturbation already occurred in terms of dissolved Cd cycling locally in the whole river–estuary system.

2. Method and materials

2.1. Study area

The Jiulong River (JR) is the 13th largest river in China, with a total catchment area of 14,700 km^2, a temperate climate and high precipitation all year (e.g., Wang et al., 2005). The average annual temperature in the watershed ranged from 19.9 °C to 21.1 °C, and the river discharge averages 470 m^3/s annually and peaks as high as 800 $m^3\,s^{-1}$ in August (e.g., Liu et al., 2008). The Jiulong River flows through the cities of Longyan and Zhangzhou until the Xiamen Bay, which covered a wide agricultural area in the watershed including pig farms and crop fields (e.g., Hong et al., 1999; Zeng et al., 2006), and also the industrial and sewage effluents near the estuary (Cao et al., 2005).

The Jiulong River estuary (JRE) is characterized with semi-diurnal tides, and seawater from the Taiwan Strait could arrive as far as 20 km upstream. In our study, the Jiulong River Estuary is divided into three parts (Fig. 1) according to its geochemical and geomorphologic settings: the upper estuary, characterized with several narrow channels and freshwater outflow; the middle estuary, wide water body with a salinity range of 10–25; and the lower estuary, mainly mixing with seawater from the Taiwan Strait.

2.2. Sampling

Several cruises were conducted in the whole JRE system from the upper river to the estuary until the coastal waters during 2008–2010 (Fig. 1). The river water samples were collected in Spring and Summer under different river discharge periods: August 2008 (590 $m^3\,s^{-1}$) and May 2009 (430 $m^3\,s^{-1}$), respectively. Two cruises in the estuary were conducted via the R/V Haiyang-1 in Summer (August 2008) and Fall (November 2008): river discharges were 590 $m^3\,s^{-1}$ and 180 $m^3\,s^{-1}$, respectively. Coastal waters in the western Taiwan Strait were collected via the R/V Yanping in October 2010 (freshwater discharge from the Jiulong River: ~400 $m^3\,s^{-1}$).

The river water samples were pumped on site at the depth of ~0.2 m below surface and ~3 m away from the riverside by using an extended pole and tube. Similarly, water samples in the estuary and coastal waters were taken by using a peristaltic pump with C-Flex tubing. Generally, the intake was extended ~3 m up-current from the vessel using a plastic pole and suspended ~0.2 m below the surface to take surface samples, and ~1 m above the bottom for bottom sampling. All samples for dissolved Cd were filtered on site using acid-cleaned inline polypropylene capsule filters (0.22 μm) attached to a peristaltic pump. Filtered samples were then collected in acid-washed high-density polyethylene bottles via the outtake and acidified to pH < 1.8 with 6.0 N HNO_3. Bottles with samples were then double-bagged and stored in a refrigerator (−4 °C), and later held in the laboratory for at least one month until further processing.

Water quality parameters (salinity, and dissolved oxygen) were

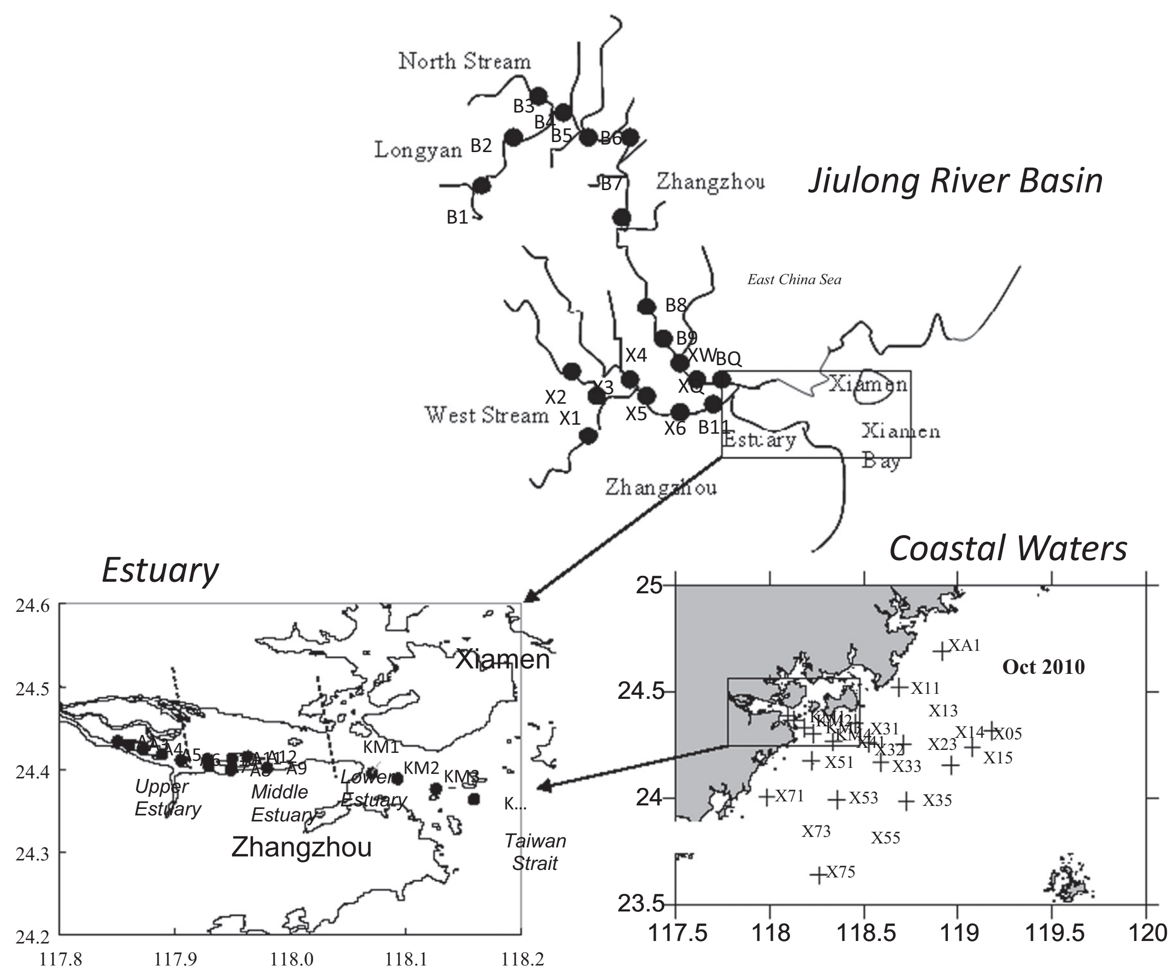

Fig. 1. Map of all the sampling locations from the Jiulong River basin, its estuary and coastal waters in the western Taiwan Strait.