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Evaluation of heavy metal contents and Pb isotopic compositions in the Chao Phraya River sediments: Implication for anthropogenic inputs from urbanized areas, Bangkok

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ABSTRACT

In order to elucidate the sources of metals in urbanized areas, heavy metal contents and Pb isotope ratios were determined in the Chao Phraya River sediments. The sediment samples were leached using 1% HNO_3 and metal concentrations (Cd, Cu, Cr, Pb, and Zn) and Pb isotopic ratios ($^{208}Pb/^{206}Pb$ and $^{207}Pb/^{206}Pb$) in the solutions were analyzed by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). The highest ranking of potential pollutant evaluations of Cd, Cu, Cr, Pb, and Zn contents was found from samples that were located near to the center of Bangkok. Pb isotope ratios ($^{208}Pb/^{206}Pb$: 2.075–2.113 and $^{207}Pb/^{206}Pb$: 0.834–0.868) in the Chao Phraya River sediments near to the center of Bangkok agreed well to those in the Bangkok road side dust and pond sediments suggesting that river sediments may be contributed from road-side dust and pond sediments. Moreover, Pb isotope ratios confirmed that the polluted sediments were contributed as Pb products of fly ashes (municipal waste combustors) in Bangkok ($^{208}Pb/^{206}Pb$: 2.100–2.120 and $^{207}Pb/^{206}Pb$: 0.867–0.870).

1. Introduction

Heavy metals have become increasingly important in environmental media because they are potentially toxic for human health. Their concentrations vary markedly in the environment, partly in relation to geologic settings and partly as a result of anthropogenic activity (Kim et al., 1998; Wu et al., 2011). Heavy metals are potentially taken up by river sediments and accumulated in the food chain (Burton, 1992). Because of its ability to sequester heavy metals, river sediment is an important storage for recording the effects of anthropogenic activities (Bird et al., 2005; Segura et al., 2006; Sjobakk et al., 1997). The quality of river sediment is essential in assessing the pollution status of the ecosystem.

The Chao Phraya River, the largest river in Thailand, is heavily affected by a variety of anthropogenic activities along its length (Cheevaporn and Menasveta, 2003). The Chao Phraya River passes through Bangkok, the capital city of Thailand. The pollutants flowing into the river are contributed from the wastes of the cities located along its bank. There, it receives large volumes of domestic, agricultural and industrial effluents. There are numerous sources of domestic and industrial effluents which lead to heavy metal enrichment in water and sediments. A study in the Bangkok Metropolitan area by Taranatham (1992) estimated that 60–70% of domestic waste is eastern discharged into the Chao Phraya River and eventually into the Gulf of Thailand without being treated. These untreated wastes are discharged directly or indirectly into canals, rivers and the ocean leading to high Biochemical Oxygen Demand (BOD) values and bacterial contamination close to populated and industrialized areas. In addition, Polprasert (1982) also reported high concentrations of Cd, Cu, Cr, Pb, Zn and Hg in the waters and sediments of the Chao Phraya River estuary in 1979.

Knowing only the level of heavy metal concentrations is not sufficient for a precise evaluation of contamination sources. By contrast, Pb isotope is a very efficient tool for tracing the sources of environmental pollution (Farmer et al., 1997; Komarek et al., 2008). Hirao et al. (1986) reported that Pb isotope ratios had been used to trace the origin of contamination in river sediment. The Pb isotope ratios, $^{208}Pb/^{206}Pb$ and $^{207}Pb/^{206}Pb$, have been utilized with great success to trace the sources of pollution and to distinguish different sources from specific pollutants in sediments (Hosono et al., 2010; Swennen and Van der Sluys, 2002; Walraven et al., 1997; Wijaya et al., 2012). However, only

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Table 1
Heavy metal and aluminum contents, including enrichment factor (*EF*) in the Chao Phraya River sediments.

Sampling location	Cd (mg/kg)	Cu (mg/kg)	Cr (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	Al (%)
September 3–20, 2008						
81 km	0.14 (1.00)	9.72 (1.00)	5.52 (1.00)	18.0 (1.00)	19.7 (1.00)	0.11
72 km	0.13 (0.47)	14.3 (0.75)	4.72 (0.44)	15.1 (0.43)	21.9 (0.57)	0.22
64 km	0.15 (0.47)	15.1 (0.75)	3.27 (0.44)	15.4 (0.43)	39.6 (0.57)	0.17
60 km	0.14 (0.69)	11.1 (0.79)	3.97 (0.50)	11.2 (0.43)	27.4 (0.96)	0.16
58 km	0.18 (0.92)	11.3 (0.83)	3.23 (0.42)	12.9 (0.51)	38.7 (1.41)	0.16
53 km	0.17 (1.81)	16.0 (2.46)	4.07 (1.27)	22.9 (1.90)	45.8 (3.47)	0.08
50 km	0.25 (1.30)	29.3 (2.19)	6.43 (0.85)	26.4 (1.07)	130 (4.79)	0.15
44 km	0.23 (1.94)	38.4 (4.66)	6.75 (1.44)	30.6 (2.01)	127 (7.60)	0.09
40 km	0.34 (2.74)	50.8 (5.89)	26.3 (5.37)	38.8 (2.43)	134 (7.67)	0.10
36 km	0.15 (0.45)	6.59 (0.28)	6.26 (0.47)	10.8 (0.25)	24.7 (0.52)	0.27
32 km	0.31 (2.11)	50.1 (4.99)	8.77 (1.51)	28.0 (1.48)	116 (4.44)	0.19
27 km	0.22 (1.65)	42.3 (4.58)	7.78 (1.48)	28.8 (1.68)	103 (5.55)	0.11
March 11, 2009						
72 km	0.08 (1.00)	12.7 (1.00)	4.41 (1.00)	14.7 (1.00)	26.7 (1.00)	0.20
58 km	0.58 (7.63)	61.0 (5.06)	9.11 (2.17)	25.9 (1.85)	183 (7.21)	0.19
56 km	0.39 (3.25)	117 (6.14)	50.9 (7.69)	50.5 (2.29)	200 (4.99)	0.30
55 km	0.36 (2.57)	31.1 (1.40)	6.18 (0.80)	30.0 (1.17)	230 (4.92)	0.35
54 km	0.14 (2.50)	24.8 (2.79)	8.40 (2.72)	30.3 (2.94)	42.3 (2.26)	0.14
53 km	0.25 (6.94)	37.1 (6.49)	9.98 (5.03)	20.5 (3.10)	70.9 (5.90)	0.09
52 km	0.24 (2.22)	23.6 (1.38)	6.81 (1.14)	25.2 (1.27)	55.4 (1.54)	0.27
51 km	0.24 (3.75)	39.8 (3.92)	8.33 (2.36)	17.8 (1.51)	62.5 (2.93)	0.16
50 km	0.24 (2.61)	52.9 (3.62)	9.15 (1.80)	33.6 (1.99)	86.4 (2.81)	0.23
49 km	0.42 (9.55)	167 (23.9)	33.6 (13.8)	40.0 (4.95)	171 (11.6)	0.11
48 km	0.27 (2.50)	53.3 (3.11)	17.9 (3.01)	31.2 (1.57)	91.8 (2.55)	0.27
40 km	0.40 (10.0)	66.7 (10.5)	63.2 (28.7)	32.3 (4.39)	182 (7.67)	0.10
36 km	0.34 (3.86)	103 (7.37)	42.6 (8.78)	39.2 (2.42)	142 (4.83)	0.22
29 km	0.37 (3.70)	56.5 (3.56)	26.6 (4.83)	136 (7.40)	194 (5.81)	0.25
27 km	0.22 (1.77)	37.1 (1.88)	43.5 (6.36)	25.2 (1.11)	78.8 (1.90)	0.31
November 7, 2009						
72 km	0.08 (1.00)	11.0 (1.00)	5.06 (1.00)	12.5 (1.00)	17.1 (1.00)	0.22
58 km	0.16 (1.33)	33.7 (2.04)	9.75 (1.28)	30.1 (1.61)	69.0 (2.69)	0.33
56 km	0.36 (1.74)	113 (3.96)	15.0 (1.14)	39.4 (1.22)	193 (4.36)	0.57
55 km	0.26 (3.40)	44.4 (4.23)	6.05 (1.25)	30.1 (2.52)	113 (6.92)	0.21
54 km	0.11 (0.95)	11.7 (0.73)	2.85 (0.39)	12.9 (0.71)	44.7 (1.80)	0.32
53 km	0.10 (0.92)	17.7 (1.18)	3.09 (0.45)	15.1 (0.89)	44.7 (1.92)	0.30
52 km	0.24 (2.44)	23.6 (1.75)	6.81 (1.10)	25.2 (1.64)	55.4 (2.64)	0.27
51 km	0.12 (1.38)	17.4 (1.45)	3.14 (0.57)	17.8 (1.31)	57.3 (3.07)	0.24
50 km	0.24 (1.89)	58.5 (3.34)	5.78 (0.72)	103 (5.18)	116 (4.26)	0.35
49 km	0.18 (0.90)	38.4 (1.40)	4.91 (0.39)	117 (3.74)	134 (3.13)	0.55
48 km	0.29 (2.35)	115 (6.76)	9.06 (1.16)	30.9 (1.60)	180 (6.81)	0.34
40 km	1.04 (11.0)	213 (16.4)	50.7 (8.48)	98.1 (6.64)	643 (31.8)	0.26
36 km	0.24 (1.43)	75.5 (3.28)	12.0 (1.13)	38.8 (1.48)	192 (5.37)	0.46
29 km	0.32 (1.49)	53.9 (1.83)	10.8 (0.80)	22.9 (0.68)	237 (5.17)	0.59
27 km	0.12 (0.56)	49.7 (1.68)	10.4 (0.77)	812 (24.2)	127 (2.77)	0.59
Background sediments						
September 3–20, 2008						
81 km	0.14	9.72	5.52	18.0	19.7	0.11
March 11, 2009						
72 km	0.08	12.7	4.41	14.7	26.7	0.20
November 7, 2009						
72 km	0.08	11.0	5.06	12.5	17.1	0.22
Crust	0.10	25.0	126	14.8	65.0	7.96
Sediments (World)	0.30	0–192	–	20.0	2–1000	–
Unpolluted sediments	0.30	34.0	–	22.0	97.0	–

(–): not determined.
Crust: Wedepohl (1995); world sediments: Rankama and Sahama (1960); unpolluted sediments: Mudroch et al. (1998).

few studies of heavy metals and Pb isotopes in the Chao Phraya River sediments have been reported (Mukai et al., 1993; Polprasert, 1982). Therefore, the evaluation of heavy metals and Pb isotope ratios in the aquatic environment of Thailand is still poorly known.

In this paper, we present the evaluation of heavy metal contents such as Cd, Cu, Cr, Pb, and Zn metals including Pb isotope ratios in the Chao Phraya River sediments at various sampling locations. Pb isotope ratios were studied to view the importance and benefits of their usage in environmental pollution studies.

2. Material and methods

2.1. Sample collection

River sediment samples were taken at 12 sites on September 3, 2008. Sites started from 81 km upriver going downriver to a site 27 km from the river mouth. We also collected samples at 15 sites on March 11, 2009 and at another 15 sites on November 7, 2009. Sites started from 72 km upriver going downriver to a site 27 km from the river mouth (Table 1). The sampling locations are given in Fig. 1. The sediment samples were taken from the surface of the river bottom using a stainless-steel grab. The grab was carefully opened over a plastic bowl. Then, inside-out plastic bags were used to pick up the surface samples from the plastic bowl.

In order to monitor metal pollution from urbanized areas, we also collected Bangkok road-side dust and pond sediment samples (Table 5). A reference sample of a pristine beach, Kamala beach sand, was collected from Phuket. Phuket is located on the western shore of Thailand facing the Andaman Sea. This area is known to be cleaner than the upper part of the Gulf of Thailand. Therefore, this sample was taken to compare with the Bangkok road-side dust and pond sediment samples.

Road-side dust, pond sediment and beach sand samples were picked up in a similar manner using inside-out plastic bags. Some samples were taken directly from the side of the street/pond/beach sites while others were shuffled up using medicine paper then put into the plastic bags. Plastic bags were tightly closed using a simple knot and then