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Metal Concentrations in Sediments of the Tamsui River, Flows Through Central Metropolitan Taipei

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Abstract This work analyzed metal concentrations and potential sources of sediment pollutants in the Tamsui River, Taiwan, by instrumental neutron activation analysis. The Tamsui River, the second longest of Taiwan's three major rivers, flows through metropolitan Taipei City in northern Taiwan and is renowned for its preserved mangrove wetlands. In total 11 elements Al, As, Br, Cs, Fe, La, Mg. Mn, Na, Sc, and Ti were identified in 24 samples taken from three sites upriver, the mangrove area and estuary during the spring of 2004. Specifically, the most abundant Al metal concentration was 15.6–0.92 mg/g adopted as standard reference in this study. Only few sites had As at the statistical meaning (>DL). Furthermore, arsenic concentrations fluctuated at roughly 0.67 ± 0.09 mg/kg based on variations in background counts in various γ-ray spectra. Elemental concentrations of these elements were compared with those in other nations, and discussed in the context of enrichment factors calculated for elements using the earth crust of various sediments as references, based on elemental values of Al.

Keywords Sediments · Metals · Tamsui River · Mangrove · Instrumental neutron activation analysis · Enrichment factor

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Environmental hygiene in metropolitan Taipei, Taiwan, has attracted considerable attention over the last 30 years. The population of Taipei has increased to nearly six million, roughly one-quarter of Taiwan's total population. Local anthropogenic sediments are the result of environmental hygiene, extremely high vehicle traffic, and industrial emissions. However, a lack of adequate sewage systems and other related facilities means that approximately 70% of industrial and domestic waste flows into the Tamsui River, the second longest of Taiwan's three major rivers, which drains into the Taiwan Strait. Contaminants and metals are slowly deposited along the shorelines of the river. Additionally, metal contamination typically occurs upriver, and in the mangrove area and estuaries. Data for metal concentrations in the Tamsui River are scarce and generally restricted to certain analytical methods. Metals in mangrove environments have garnered increased attention as sediment in this forest is both a sinks and source of pollution in the

Tamsui River. Many studies have analyzed metal concentrations in sediments along the river shorelines. Complex pre/post treatment of conventional samples has led researchers to develop widely applicable methods for qualifying metal concentrations that have increased precision. Numerous spectroscopic techniques such as instrumental neutron activation analysis (INAA) (Chen 2006; Mubiana and Blust 2006; Dinescu et al. 2004; Chen et al. 2003; Chen and Pan 2001; Waheed et al. 2001; Al-Jundi 2000), atomic absorption spectroscopy (AAS) (Machado et al. 2002; Aloupi and Angelidis 2001; Fang and Hong 1999; Tam and Yao 1999; Lee et al. 1998; Kao and Chang 1998), inductively coupled plasma mass spectrometry (ICP-MS) (Jingchun et al. 2006; Sharma et al. 1999; Schuhmacher et al. 1997), and X-ray Absorption Spectroscopy (EXAFS) (Wang et al. 2003) can measure heavy metal concentrations in sediment. Applying INAA, as utilized herein, can bridge the gap between precise measurement and easy preparation, and satisfy modern environmental hygiene criteria. The INAA, which rapidly and accurately determines concentrations of many metals, is a non-destructive and multi-elemental method, without the problems associated with dissolution of complex samples, and without possible contaminations associated with sample pretreatment (Chen and Pan 2001). Accordingly, this work evaluates the concentrations of 12 metals from 24 different locations along river shorelines, and elucidates the relationships among these metal based on various sampling positions. Although many studies have analyzed sediment, few have focused on metropolitan Taipei. Arsenic in ground-water is a well-documented risk factor for Blackfoot disease in southern Taiwan (Chen 2006; Wang et al. 2003). The Environmental Protection Agency (EPA) of the Republic of China, Taiwan (ROC) recommends that arsenic levels in drinking water not exceed 50 μg/L (EPA 1997). The Erh-jen River in Taiwan and its estuary have high metal contamination (Chen 2006; Wang et al. 2003). Manganese and iron are common in industrial effluent and other anthropogenic sources of contamination in sediment in mangrove areas (Tam and Yao 1999). However, in excess amounts, these elements, especially As, Mn, and Fe, are toxic to plants, and enter water systems through surface run-off and leaching (Lee et al. 1998). This is the first study to evaluate arsenic concentrations in a mangrove area and is very important to establish baseline data for metal concentrations such that pollution along the Tamsui River can be assessed.

The Tamsui River is 159 km long and has a flood area of 2726 km^2. The Tamsui River flows through central metropolitan Taipei, Taiwan's largest city with a population of roughly six million. Taipei is located in northern Taiwan, and is surrounded by eight major satellite cities. The river serves many roles; for example, the river is an open and free sewage system for residences upriver. As an urban river, the Tamsui River is, uniquely, an area for natural preservation of almost 54 acres mangroves (Kao and Chang 1998). This area primarily consists of *Kandelia candel (L.) Druce* forest, and some other mangrove species, such as *Gruguiera Gymnorrhiza*, *Vitex rotundifolia, Wedelia biflora,* and *Bidens Bipinnata (L.)*. The river is home to one of the best *Kandelia candel (L.) Druce* forests in Taiwan, which is protected by the ROC government. Mangrove ecosystems, which are intertidal, are reduced in numbers gradually. These features promote the retention of metals from inland freshwater drainage and tidal flushing (Tam and Yao 1999). This river also supports short-range transportation ($\sim$15 km) near the Tamsui estuary. Many bridges cross this river, connecting northern and southern parts of Taipei City. This convenient transportation system facilitates communication among satellite cities and promotes garbage dumping along the river shorelines.

Materials and Methods

Sediments were obtained from 24 positions using a Teflon-coated Ekman Dredged along either side of the Tamsui River during March to May in 2004 (25°11′N, 121°30′E to 25°05′N, 121°22′E). The precise sampling positions were depicted in Fig. 1. The labels in the figure were clearly grouped among three sites referring to the human activities, that is, upriver, mangrove area and estuary, respectively. The sediments were collected from 35 to 45 cm deep beneath the river bed and then dried in an oven until a constant weight was achieved, then ground with a pestle and mortar and screened using a 300 pinhole/in sieve (Tam and Yao 1999). Each treated sediment sample, weighting 160 ± 10 mg, was packed into a 3 × 3 cm^2 polyethylene (PE) bag to be irradiated with neutrons (Chen and Pan 2001). An empty PE bag of identical size was employed as a blank correction. Each bag was subsequently wrapped in "clean" PE to prevent contamination before irradiation. Samples of sediments and reference materials were prepared in triplicate to minimize statistical uncertainty (Chen and Pan 2001).

These samples were irradiated in a zero-power reactor at LungTan (ZPRL) with a neutron flux of 7.5×10^{11} n · cm^{-2} s^{-1} (Tsao and Pan 2000). The activated samples were divided into those that were irradiated for a short period (5 min) and those that were irradiated for a long period (20 h). Radiations from the briefly irradiated samples were counted after they had been cooled for 5 min. Radiation from the 10 ± 3 mg nickel powder irradiated together with each of the samples was also counted to correct the neutron fluctuation during irradiation. Radiation from the samples and reference materials irradiated for a

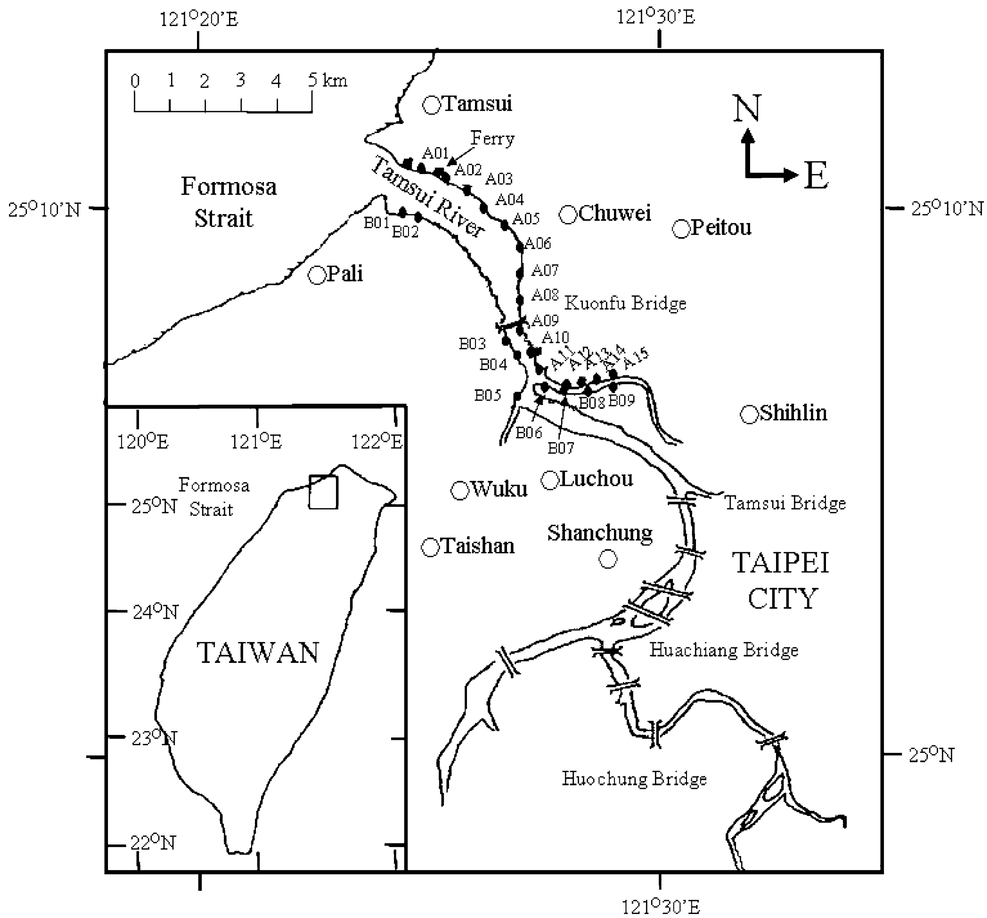

Fig. 1 Sampling positions along the Tamsui River in this study. Samples were labeled into three sites, upriver, mangrove and estuary for various human activities

long time was counted in two stages, according to the radionuclide decay property in the activated sample. Radiation from one group of samples was counted for 4,000 s after a 3 to15 day decay period; while the other was counted for 20,000 s after 15 days (Chen and Pan 2001; Waheed et al. 2001; Tsao and Pan 2000). The activated sample was analyzed by a γ-ray detecting system that consisted of a high purity germanium (HPGe) detector with a 15% relative efficiency and a multi-channel analyzer (MCA). The efficiency of the HPGe detector was determined with a series of γ-energy using calibrated standards for ^{60}Co, ^{133}Ba, ^{137}Cs, and ^{152}Eu. Additionally, the results were calibrated to 160 ± 10 mg reference material IAEA SL-7 (sediments from International Atomic Environmental Agency) with the same geometry in irradiation rabbit. The decay properties for the relevant radionuclide are listed in Table 1 (Dinescu et al. 2004; Chen and Pan 2001; Al-Jundi 2000; Shirley and Lederer 1978).

The Detection Limit (DL) calculated herein was defined as follows (Chen and Pan 2001).

$$DL_{(sample)} = \frac{MDA_{(sample)}}{MDA_{(std)}} C_N K_f \quad (1)$$

Table 1 Radioactive decay properties of metals assayed in this work

Radionuclide	$T_{1/2}$	E_γ(keV)	I_γ (γ/decay)
Group 1			
Al-28	2.24 m	1778.9	1.000
Mg-27	9.46 m	843.8	0.718
Mn-56	2.58 h	846.8	0.989
Ti-51	5.80 m	320.0	0.948
Group 2			
Ar-76	26.5 h	559.2	0.447
Br-82	35.3 h	776.5	0.833
Na-24	15.00 h	1368.5	0.999
La-140	40.2 h	1595.4	0.955
Sc-46	83.83 d	889.2	1.000
Group 3			
Cs-134	2.19 y	604.7	0.984
Fe-59	45.0 d	1098.6	0.565
Ni-65[a]	2.52 h	1481.8	0.235

[a] The Ni-65 flux monitors were adopted for neutron flux measurement in this work

y = year, m = month, d = day, h = hour

Table 2 The evaluated results for each metal (mg/kg) in Taisui River

Element	Upriver		Mangrove		Estuary	
	Mean ± SD	Median (range)	Mean ± SD	Median (range)	Mean ± SD	Median (range)
Al	39900 ± 10000	36500 (58600, 27000)	36300 ± 2660	36300 (39800, 31700)	38600 ± 16800	41500 (55700, 15700)
As	3.30 ± 5.21	0.88 (12.6, <DL)	9.78 ± 2.53	9.40 (13.0, 7.32)	8.04 ± 1.41	8.04 (9.04, 7.04)
Br	15.4 ± 7.48	12.3 (28.6, 6.29)	23.3 ± 5.6	24.8 (30.2, 14.2)	22.6 ± 8.1	23.8 (30.9, 11.7)
Cs	6.88 ± 1.85	7.83 (9.41, 4.05)	7.58 ± 0.68	7.34 (8.54, 6.67)	7.04 ± 0.74	7.29 (7.63, 5.96)
Fe	32200 ± 4600	33900 (36500, 21200)	33100 ± 4300	33400 (37500, 24800)	34700 ± 2600	34700 (37800, 31500)
La	23.7 ± 16.1	27.1 (48.6, 10.4)	41.2 ± 3.0	42.5 (43.7, 34.9)	38.1 ± 0.9	37.9 (39.5, 37.4)
Mg	9300 ± 2200	9280 (14800, 6790)	9480 ± 900	9710 (10600, 7770)	10470 ± 2120	11200 (12200, 7400)
Mn	316 ± 82	323 (445, 208)	320 ± 82	340 (431, 185)	371 ± 123	419 (456, 191)
Na	11100 ± 1400	11800 (14700, 8760)	13400 ± 1400	13900 (14900, 10600)	14100 ± 1800	12900 (14900, 11400)
Sc	5.12 ± 4.71	6.06 (12.5, 1.35)	10.3 ± 1.2	10.7 (11.6, 8.43)	11.0 ± 1.0	11.2 (12.2, 9.68)
Ti	2810 ± 450	2740 (3590, 2090)	2640 ± 170	2690 (2800, 2260)	2630 ± 760	2660 (3510, 1690)

The Minimum Detectable Amount (MDA), which was derived according to Currie's formula (Curie 1968), follows the fluctuation of DL, where $MDA_{(std)}$ is determined for standard soil powder (IAEA SL-7) and C_N is the elemental concentrations of std (mg/kg). K_f are the concentration of standard soil powder and the conversion factor of the thermal neutron flux, respectively. According to this definition, the MDA is derived as:

$$\mathrm{MDA} = \frac{K \cdot (2.71 + 4.65\sqrt{B})}{\phi \cdot \sigma_{\mathrm{th}} \cdot M \cdot \varepsilon(E_r) \cdot I_\gamma(E_\gamma) \cdot S \cdot D \cdot C} \quad (2)$$

where K represents the overall calibration factor during the chemical process; B is the integrated number of background counts under the gamma peak of interest; ϕ is the effective thermal neutron flux ($n \cdot cm^{-2}/s$); σ_{th} is the thermal neutron cross section (cm^2); M represents the sample weight (g); $\varepsilon(E_r)$ and $I_\gamma(E_\gamma)$ represents the detection efficiency and intensity of the γ-ray, respectively; S; D and C are related to the saturation factor, decay factor, and counting factor of the sample as $1 - e^{-\lambda t_i}$; $e^{-\lambda t_d}$; and $1 - e^{-\lambda T_c}/\lambda$, respectively. The counting errors increase up to 10% for a few elements such as As, Cs, Mg, and Ti. In this case, it is due to primary to low concentrations of those elements in some sediment which increase the fluctuation of the counting statistics or because of strong background interference from other radioactive γ-ray. The analytical errors of the results for most metals were within 15% except the derived DL for arsenic fluctuated around 0.67 ± 0.09 mg/kg based on the related background counts of each γ-ray spectrum.

Analytical results will generate a database that will facilitate the development of environmental strategies for metals in sediment from Taipei City. Table 2 lists the measured concentrations for each metal from each sampling location and the average concentrations of 11 elements determined by INAA in the sediment samples. Metal concentrations were normalized to total mean concentrations for each metal, and the normalized data were illustrated in Fig. 2. Table 2 demonstrated that upriver had the largest statistic errors As (74%), La (47%) and Sc (53%). In addition, La (2.62%) and Fe (7.8%) at the estuary had the smallest statistic errors. The overall order of sediment metal concentrations in the Tamsui River was Al > Fe > Na > Mg > Ti > Mn > La > Br > Sc > Cs > As. Comparisons of maximum, minimum, mean and range of concentrations of all elements indicates that concentrations vary widely; that is, they were not uniform throughout the Tamsui River and varied from position to position among locations, suggesting that the sources of most elements are anthropogenic. The largest deviations from average metal concentrations were for As (158%), Br (46%), La (68%) and Sc (92%) upriver, As (26%) and Mn (25%) at mangrove sites and Al (44%), Br (36%), Mn (33%) and Ti (29%) at the estuary.

Sediment samples were collected from different positions on the Tamsui River. This study's aim is to characterize metal distributions in surface sediments and thereby create a data-base for future geochemical studies for monitoring these metal bioaccumulations. Concentrations of the rare earth element, lanthanum were also measured herein. As lanthanum in neither toxic nor essential to environment, it has attracted little attention (Waheed et al. 2001). Lanthanum concentrations were 10.4–48.6 mg/kg, and did not differ markedly in different sediment samples.

The aluminum concentrations were highest in upriver site than elsewhere, ranging from 27000–58600 mg/kg. In addition, concentrations of As, Br, Cs, Fe, La, Mn, Na, and Sc were significantly less in upriver than elsewhere, indicating that these metals are markedly affected by local hygiene. (cf. Fig. 2) Concentrations of Na, (11100 ± 1400 mg/kg) at the A11–A15, and B03–B09 sites were lower than others as sea-water was diluted by upstream

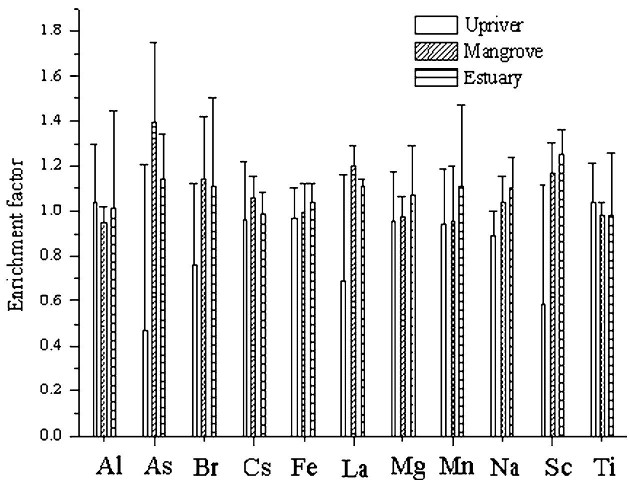

Fig. 2 Comparison of 11 metal contents in sediments of the Tamsui River among three sampling sites. (Normalized to a total mean of 3 subjects)

fresh-water and the amount of salt (NaCl) in sea water declined accordingly. Moreover, the continuous reduction in Na concentrations from the estuary to those upriver verified measurement consistency; thus, no systematic error was evident [cf. Fig. 1].

Samples obtained from sections A03–A10 were located on right side of the mangrove area along the Tamsui River at Chuwei (Kao and Chang 1998) [cf. Fig. 1]. Some studies determined that twisted roots and intricate gnarls of *Kandelia candel (L.) Druce* can contain small amounts of minerals (Kao and Chang 1998; Huang and Chen 1995). As the mangroves are close to urban Taipei City, the metal concentrations in the mangrove area reflect anthropogenic pollution (Machado et al. 2002; Tam and Yao 1999). Specifically, arsenic was found principally in this area (A03–A05), ranging from 13.2 to 7.32 mg/kg. Notably, As, Br, Cs, and La were found the highest concentrations than those of other sites. Other elemental concentrations, such as those for Al, Fe, Mg, Mn, Sc, and Ti, were consistent at different sites. Additionally, the Al concentration ranged from 31700 to 39800 mg/kg; the maximum concentration was at site A06. The Na concentrations in sediment were roughly 19% that of measured in 1998 by Kao and Chang (Kao and Chang 1998). The A05 position was close to the estuary and had a higher arsenic concentration (12.99 mg/kg) than that at other locations, which more remote and generally undisturbed by humans.

Positions A01 and A02 and B01 and B02, are located on the Tamsui River estuary[cf. Fig. 1]. However, the evaluated concentrations of most nuclides were not different between two sides of Tamsui River. Metal concentrations on the right (A01 and A02) and left (B01 and B02) side of Tamsui River deviated randomly from the mean concentration [cf. Table 2]. Iron concentrations in sediment were 31500–37800 mg/kg; concentrations of Mg, Mn, Na, and Sc were higher in estuary area than those at other sites. Several factors that may have increased metal bioaccumulations upriver to levels higher than other sites would be expected based on the degree of environmental contamination. Metal sources are typically industrial waste, discharged sewage effluent and harbor activity. Moreover, the distribution of arsenic varied markedly among sample locations. Thirteen of the 24 sample sites contained almost no As or less than the DL. Only 11 locations had As concentrations that fluctuated widely from 0.80 to 12.99 mg/kg with a range of over 16.2 times the difference between the minimum and maximum concentration. Most large As concentrations were around A02–A05 in the mangrove area. Schuhmacher et al. demonstrated that the most likely mean concentration of As in uncontaminated soils was 7.6 mg/kg (Schuhmacher et al. 1997). There was preferentially arsenic contamination at A02–A05 and A15 sites, meaning that these positions contribute significantly to increase arsenic contamination risk. Additionally, these sampling sites included ferry landing sites and public transportation stations at Tamsui. Thus, pollution can affect residents and tourists and is a public health issue.

The enrichment factor (EF) is a dimensionless indicator of the status of metal pollution (Aloupi and Angelidis 2001; Waheed et al. 2001; Sharma et al. 1999; Lee et al. 1998). If the source of an element is only the earth's crust, the EF for that element will be unity. The Al concentration in sediment is primarily due to natural weathering processes and has been utilized to normalize metal contents (Waheed et al. 2001; Sharma et al. 1999; Lee et al. 1998). The concentration of Al can be measured accurately using INAA by identifying the radionuclide ^{28}Al with 1778.9 keV γ-line. According to the Handbook of Chemistry and Physics, the metal EF of the earth's crust can be expressed as follows: (Lide 2006–2007);

$$\mathrm{EF_{Al}} = (C_x/C_{\mathrm{Al}})_{\mathrm{sediment}}/(C_x/C_{\mathrm{Al}})_{\mathrm{background}} \qquad (3)$$

where $(C_x/C_{\mathrm{Al}})_{\mathrm{sediment}}$ is the ratio of concentrations of element X to the Al concentrations as the reference nuclide (X) metal of the sediment in this work, and $(C_x/C_{\mathrm{Al}})_{\mathrm{background}}$ is the same ratio in the background. Background values were acquired for earth crust not exposed to industrial pollution (Lide 2006–2007). As background values for metal at the study area do not exist, this study adopted the following values for the earth's crust; Al, 8.24×10^4 mg/kg; As, 1.8 mg/kg; Br, 2.4 mg/kg; Cs, 3 mg/kg; Fe, 5.63×10^4 mg/kg; La, 3.9×10^1 mg/kg; Mg, 2.33×10^4 mg/kg; Mn, 9.50×10^2 mg/kg; Na, 2.36×10^4 mg/kg; Sc, 2.2×10^1 mg/kg; Ti, 5.65×10^3 mg/kg respectively. However, an EF value exceeding unity suggests concentrations exceeding those of the earth's crust, indicating possible pollution or chemical fractionation of

Table 3 Results of EF analysis for metals in different sampling sites

Element	Upriver	Mangrove area	Estuary
As	**3.73**	**12.3**	**9.53**
Br	**12.0**	**22.0**	**20.1**
Cs	**4.42**	**5.73**	**5.01**
Fe	1.12	1.33	1.31
La	1.24	**2.40**	**2.09**
Mg	0.81	0.92	0.96
Mn	0.68	0.77	0.83
Na	0.96	1.29	1.18
Sc	0.47	1.07	1.07
Ti	1.01	1.06	0.99

Data with EF values larger than 1.5 are presented in bold type

sediments. Most elements have an EF close to unity, indicating that the element concentrations are close to those of the crust, verifying the absence of anthropogenic activity. Averaged EFs of three sampling sites are presented in Table 3. Table 3 presents the average EFs of three sampling sites; the EF values >1.5, are in bold type. Only Br in the mangrove and estuary had an EF > 20, and As and Cs EFs were > 1.5 indicating that metal concentrations in sediment are strongly affected by human activity and the local environment and may result from element concentrations in disintegrated fragments. The high concentrations of As, Br and Cs in sediment can also be attributed to uptake of these elements from soil polluted by industrial and anthropogenic activities. The EF values for Fe, Mg, Mn, Na, Sc and Ti were <1.5, indicating additional pollution may contribute to the additional amounts of Al, and the decreasing ratio of these elements to the Al concentration in sediment. A high EF value at the mangrove sites indicates that the area is more polluted than other areas. Industrial activity upriver may introduce these metals into Tamsui River sediment, and are then transported to the mangrove and estuary sites. Sediment can accumulate metals and other contaminants over time which likely occurred in the mangrove area on the shore of the Tamsui River. Thus the mangrove sediment acts as a sink for heavy metals. Mangrove ecosystems favor the retention of metals from freshwater drainage and tidal flushing.

The mean levels of metals in sediment samples were similar to, or lower than, those found in recent studies of metal pollution of sediment in different counties. However, analytical data in this study indicated that Mn and Fe concentrations in the mangrove area are slightly higher than those in sediment in a mangrove area in Hong Kong; these higher concentrations are primarily due to human activities, indicating serious pollution of the Tamsui River (Tam and Yao 1999). Conversely, the levels of these metals in Tamsui River sediment are characteristic of polluted sediment. The concentrations of As, Mn, and Fe in this study are lower than those reported by Izquierdo et al.,

Table 4 Arsenic, Iron and Manganese concentrations determined in sediment by other researchers in other positions (dry weight, mg/kg)

Area (Country)	As	Fe	Mn	Reference
Upriver				
Tamsui (Taiwan)	3.30 ± 5.21	32200 ± 4600	316 ± 82	This work
Magdalena-Almejas (Mexico)	11 ± 7	N.D.	N.D.	Shumilin et al. 2005
Danube (Romania)	7.3	34000–40000	1110	Dinescu et al. 2004
Zarka river (Jordan)	2.2–5.29	8100–29000	181–613	Al-Jundi 2000
Tamsui (Taiwan)	N.D.	27000–35000	362–1175	Fang and Hong 1999
Southern (Taiwan)	N.D	14000–26000	186–635	Fang and Hong 1999
Mangrove				
Tamsui (Taiwan)	9.78 ± 2.53	33100 ± 4300	320 ± 82	This work
Guanabara (Brazil)	N.D.	N.D.	71.3–273	Machado et al. 2002
Ckek Keng (Hong Kong)	N.D.	20400 ± 3000	224.9 ± 18.0	Tam and Yao 1999
Sai Keng (Hong Kong)	N.D.	20600 ± 1200	65.8 ± 8.6	Tam and Yao 1999
Estuary				
Tamsui (Taiwan)	9.04 ± 0.90	34700 ± 2600	371 ± 123	This work
Western Scheldt (Belgium, polluted)	N.D.	4318 ± 250	86.6 ± 4.3	Mubiana and Blust 2006
Eestern Scheldt (Belgium, unpolluted)	N.D.	4229 ± 291	133 ± 4.6	Mubiana and Blust 2006
Antarctic (Marine)	5.2	13000	365	Waheed et al. 2001
Tamsui (Taiwan)	N.D.	27000–35000	362–1175	Fang and Hong 1999
Odiel Salt Marsh (Spain)	81 ± 4	40200 ± 2200	563 ± 50	Izquierdo et al. 1997
Bay of Cadiz Salt Marsh (Spain)	9 ± 1	7600 ± 290	363 ± 41	Izquierdo et al. 1997

N.D: not determined

who analyzed the sediment on the southern Atlantic Coast of Spain (Izquierdo et al. 1997). Experimental results in this study are in good agreement with those obtained by studies of the Jiulong River, Fujian in southern China (Jingchun, et al. 2006) (Table 4). Experimental results also agreed well with those obtained by Kao and Chang (Kao and Chang 1998), who measured metal concentrations along the Tamsui River and acquired a similar conclusion using a chemical analysis technique (Kao and Chang 1998). Furthermore, Fe concentrations in the estuary were in good agreement to those measured in southwestern Taiwan in 1998 (Lee et al. 1998). Thus, INAA as adopted herein was an accurate and reliable technique for environmental metal analysis. High concentrations of Mn and Fe were likely derived from heavy industrial activities during the past decades that were located around the Tamsui River, which flowed through Metropolitan Taipei.

Metals in sediments have received increased attention in recent years due the growing awareness of environmental issues. The most abundant Al metal concentration was 15.6–0.92 mg/g adopted as standard reference in this study. Arsenic concentrations were 12.99–0.80 mg/kg. Only few sites had As at the statistical meaning (>DL). The concentrations of Mn and Fe at the mangrove sites were high; therefore, the inhabitants of Taipei City and surrounding residential areas are exposed to high levels of pollutants and at increased health risk. The experimental results in this study agreed well with those obtained by previous studies, thereby proving that INAA was an accurate and reliable technique for environmental analysis. Discharged industrial and domestic waste into the Tamsui River has elevated concentrations of As, Fe, and Mn in river sediment. Finally, analytical data in this study can assist the Taipei government in developing a Tamsui River management strategy to limit the spread of metals and protect public health.

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