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High levels of heavy metals in rice (*Oryza sativa* L.) from a typical E-waste recycling area in southeast China and its potential risk to human health

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Abstract

Very few studies have investigated the heavy metal contents in rice samples from a typical E-waste recycling area. In this study, 10 heavy metals (As, Ba, Cd, Co, Cr, Cu, Hg, Mn, Ni and Pb) in 13 polished rice and relevant hull samples, six relevant paddy soil samples were investigated. The geometric mean concentrations of Cd, Cu and Hg in soil samples were 1.19, 9.98 and 0.32 μg g^{-1}, respectively, which were 4.0, 2.0 and 1.1-folds of the maximum allowable concentration (MAC) (0.30, 50.00, 0.30 μg g^{-1}, respectively) for Chinese agricultural soils. The analyzed metal concentrations were significantly different between rice and relevant hull except for As, Cd and Hg ($p < 0.05$). All metal concentrations, except for Co, in rice hull were higher than those in polished rice. The geometric mean of Pb in polished rice reached 0.69 μg g^{-1}, which was 3.5-folds higher than the MAC (0.20 μg g^{-1}) by the safety criteria for milled rice. Cd contents in 31% of the rice samples exceeded the national MAC (0.20 μg g^{-1}), and the arithmetic mean also slightly exceeded national MAC. In addition, Cd and Pb contents in local rice were much higher than commercial rice samples examined in this work and previous studies. Comparing the tolerable daily intakes given by FAO/WHO with the mean estimated daily intakes; Pb daily intake through rice consumption in this area was 3.7 μg day^{-1} kg^{-1} body weight (bw), which already exceeded the FAO tolerable daily intake, and the Cd daily intake (0.7 μg day^{-1} kg^{-1} bw) through rice had already taken up 70% of the total tolerable daily intake (1 μg day^{-1} kg^{-1} bw). The daily intake of Hg and As through rice was much lower than the tolerable daily intakes, but bioaccumulation of Hg through the food chain and intake of As from other food stuff should also be of concern.

Keywords: E-waste recycling; Heavy metals; Rice; Paddy soil; Estimated daily intakes (EDI); Tolerable daily intakes (TDI)

1. Introduction

The disposal of electronic and electric waste (E-waste) has caused a serious environmental problem, especially in developing countries. In China, rapidly increasing amount of E-waste from both domestic generation and illegal imports (UNEP, 2005; Widmer et al., 2005) should be mentioned. Since 1990s, a large amount of E-waste have been dismantled in Taizhou, Zhejiang Province, which is a well-known E-waste recycling centre in southeast China (Hicks et al., 2005; Zhao et al., 2006, 2007). Hundreds of small and open specialized E-waste recycling shelters or yards appear in this area. Many toxic ingredients such as lead, cadmium, beryllium, mercury, polychlorinated biphenyls and brominated flame retardants contained in these E-wastes, (Schmidt, 2002; Soderstrom and Marklund, 2002; Jang and Townsend, 2003; Wong et al., 2007) may enter

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into the environment and impose great threat to human health regardless of occupational and environmental exposure. The unregulated processing of E-waste usually recovers gold and other valuable metals by applying some simple techniques such as burning, melting, using acid chemical bath, and so on. These activities can cause severe pollution of highly toxic heavy metals (such as Cu, Cd, Pb and Hg) in aquatic and terrestrial ecosystems, and even to the atmosphere (Deng et al., 2006; Leung et al., 2006). Heavy metals are non-biodegradable, thus persisting for long periods in environmental ecosystems.

Soils contaminated by heavy metals from either aerial depositions or irrigation are likely to induce a corresponding contamination in harvested crops (Nan et al., 2002). Crops in or close to contaminated sites can uptake and accumulate these metals, and then exert potential risk to humans and animals (Gupta and Gupta, 1998; Järup, 2003). Malfunction of organs and chronic syndromes may be caused by ingestion of relatively low doses of toxic heavy metals over a long period. The major route for heavy metals exposure to humans is mainly through soil–crop–food pathway. The residual plant components, including hull, straw and the root are partly returned to the soil and partly used as an ingredient in food for livestock, which is also a possible pathway for heavy metals to enter the human body by ingesting contaminated food.

In our study area, the E-waste dismantling sites are usually situated in rural areas, and crops are grown around these areas. Recent works have studied the contamination of persistent organic pollutants such as polychlorinated biphenyls and organochlorine pesticides (Zhao et al., 2006, 2007) in local food such as rice seeds, hen eggs, and silver carp muscle. To our knowledge, very few studies have investigated the heavy metal contents in crops collected from E-waste dismantling areas and conducted the corresponding risk assessment. According to statistical data from the Food and Agriculture Organization (FAO) (2004), rice nearly provides 30% of the dietary energy supply and 20% of the dietary protein intake around the world. As rice is a staple food for daily consumption in China, especially in the region of our study site, heavy metals in rice may contribute a major part to the FAO total daily intake. Therefore, there is an increasing requirement for the study of heavy metal levels in rice sampled from E-waste areas.

Four heavy metals, As, Cd, Hg and Pb, were chosen for risk assessment because of their high toxicities or comparatively high levels in all of the collected rice samples. It is therefore necessary to determine the dose level for human, which is considered to be taken daily over a lifetime without adverse effects. Inorganic arsenic, a human carcinogen, is the most toxic form of arsenic. Cadmium is toxic to the kidney and has a long biological half-life in human. Lead has shown to be associated with damnification of central nervous system, leading to decrements of intelligence quotients in children. Mercury, particularly in its organic form, mainly exhibit neurotoxicity and teratogenicity (Baars et al., 2001).

In this study, the extent of heavy metal contamination in rice (*Oryza sativa* L.) was investigated, and relevant agricultural soils were collected from a typical E-waste recycling area, Taizhou in Zhejiang Province, southeast China. The relationship between polished rice and hull, in regards to heavy metal contents, was also discussed. Assessments of the daily dietary exposures of these metals to the local population through consumption of rice were also calculated. By comparing with the provisional tolerable weekly intakes (PTWIs) for heavy metals defined by FAO/WHO (WHO, 1993), the potential risk to the health of local inhabitants was then evaluated.

2. Materials and methods

2.1. Site description and samplings

Taizhou is the biggest E-waste recycling area in Zhejiang Province, which is located in southeast of China. The latitude and longitude of this site is 28.3°N and 121.2°E. E-waste and transformers have been illicitly processed or simply incinerated in small-sized waste metal treatment factories in the region since 1989. The corresponding environmental pollution is becoming more and more serious. Taizhou is also an important agricultural area in Zhejiang Province and rice serves as the major crop for the local people.

A total of 13 rice samples (TBI-1–TBI-13) and 6 soil (TSO-1–TSO-6) samples were collected directly from the contaminated rice paddies in November 2005. Each individual rice sample was composed of at least five sub-samples which were taken from the same rice paddy. Each topsoil sample (0–20 cm) was obtained by mixing at least five adjacent sub-samples from one paddy field (four corners and the centre; approximately $10 \times 10\ m^2$). In addition, we analyzed four commercial rice samples bought from supermarkets as references in this study, which were from non-E-waste recycling areas.

The polished rice and its hull were separated by a decorticating machine. All samples (including rice and soil samples) were dried at −52 °C under a pressure of 0.05 bar for 48 h, then grinded to fine powder and sealed in polyethylene bottles.

2.2. Sample analysis

Approximately 0.2 g of plant and soil samples were weighed and put into a PTFE digestion container. Three millilitre of concentrated nitric acid (Merck, Germany) was added to each container and the samples were predigested overnight at 60 °C. After cooling, 2 ml of 30% hydrogen peroxide (Beijing Chemical Company, China) was added. The container was placed in a stainless steel bomb, and then sealed with a screw closure to avoid any acid leakage and placed in an oven. The oven temperature was kept for 1 h at 60 °C then increased to 160 °C for another 8 h. After cooling to room temperature, the solution was transferred into a 25-ml PET bottle and diluted with Milli-Q water. Reagent blanks were processed simultaneously to deduct the error induced by the analytical procedure.

As, Ba, Cd, Co, Cr, Cu, Mn, Ni, and Pb were measured by an inductively coupled plasma mass spectrometer (ICP-MS) (Thermo 7 series, USA), while Hg was determined by an atomic fluorescence spectrometer (AFS) (AF-620, Beijing Rayleigh Analytical Instrument Company, China) after hydride generation. The instrumental parameters are listed in Table 1.

2.3. Quality assurance and quality control

Standard reference materials (SRM), including soil from a contaminated area (GBW08303), rice flour (GBW08502), and Hg content in rice flour (GBW08508), were used for validation of the analytical procedure. The heavy metal contents found in the SRMs were in good agreement with the certificate values, which confirmed the feasibility of the analytical protocols in the determination of heavy metals in rice and soil (Table 2). All analyses were performed in triplicates using the external calibration method.

2.4. Tolerable daily intake of As, Cd, Hg and Pb

The PTWIs (UNEP, 1992; WHO, 1993) which was recommended by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) showed appropriate safe exposure levels, which were used to estimate the amount of contaminants ingested over a lifetime without appreciable risk. The tolerable daily intakes (TDIs) of toxic metals such as As, Cd, Hg and Pb in this study were calculated according to the FAO/WHO's PTWIs.

2.5. Estimated daily intake (EDI) of heavy metals through rice consumption

The daily intake of metals depends on both the metal concentration in food and the daily food consumption. In addition, the body weight of the human can influence the tolerance of pollutants. The estimated daily intakes (EDI) is a concept introduced to take into account these factors. The EDI was calculated as follows:

$$\mathrm{EDI} = \frac{C \times \mathrm{Cons}}{\mathrm{Bw}} \tag{1}$$

where C is the concentration of the heavy metals in contaminated rice, Cons stands for the daily average consumption of rice in this region, and Bw represents the body weight. Based on the dietary nutrition intake level survey by Zhong et al. (2006), rice was the staple food for daily consumption, and the adult residents in this region had an average daily intake of 323 g rice per day. Their body weight was set to 60 kg in this study.

2.6. Statistical analysis

All the results were expressed on a dry weight basis. Past reports observed a log-normal distribution for heavy metals in environmental samples such as rice and soil (Watanabe et al., 1996; Zhang et al., 1996). Thus, geometric means (GM) and geometric standard deviations (GSD) were taken as representative parameters of distribution. ANOVA was applied to detect significant differences. The correlation analysis was conducted by Pearson correlation. Correlation is significant at the 0.05 level (two-tailed). All statistical analyses were performed with SPSS 13.0 for Windows release 13.0 (September 1, 2004, SPSS Inc., 1989–2004).

3. Results and discussion

3.1. Heavy metal concentrations in soils

The extent of soil contamination was evaluated by comparing the total concentrations of the involved heavy metals in soils from this area with the background values of Zhejiang Province (State environmental protection administration of China, 1993) and the maximum allowable concentrations (MAC) (GB15618-1995) of metals in agricultural soil of China. The pH values of the soil were related with the speciation and bioavailability of the heavy metals, thus the MAC in soil varied with the soil pH. The

Table 1
Instrumental parameters

ICP-MS				AFS	
Plasma power	1300 W	Analyte isotope		Hollow cathode lamp	253.7 nm
Scanning mode	Peak	As	75	PMT voltage	280 V
	Jump	Ba	137		
Channels per AMU	3	Cd	111	Primary current	40 mA
Gas flow rate/l min^{-1}		Co	59	Carrier gas	Ar, 0.8 l min^{-1}
Auxiliary	0.7	Cr	52	Hydride generation	
Cool	13	Cu	65	KBH_4 concentration	0.2% (m/v)
Nebuliser	0.89	Mn	55	HCl	1.2 mol l^{-1}
Internal standard	^{103}Rh	Ni	60	Sampling time	2 s
		Pb	208	Hydride generation time	18 s

Table 2
Analysis of SRMs

Element	GBW08303			GBW08508			GBW08502		
	Certified value	Measured value (mean ± SD)[a]	Recovery(%)	Certified value	Measured value (mean ± SD)	Recovery (%)	Certified value	Measured value (mean ± SD)	Recovery (%)
As/μg g^{-1}	10.6 ± 0.6	10.6 ± 1.7	100	–[b]	–	–	0.051 ± 0.003	0.052 ± 0.007	101
Cd/μg g^{-1}	1.2 ± 0.07	1.3 ± 0.1	108	–	–	–	0.020 ± 0.002	0.017 ± 0.001	85
Cr/μg g^{-1}	112 ± 6	94 ± 2	84	–	–	–			–
Cu/μg g^{-1}	120 ± 6	117 ± 0.6	98	3.6 ± 0.2	3.6 ± 0.02	100	2.6 ± 0.2	2.4 ± 0.03	92
Hg/μg g^{-1}	2.15 ± 0.06	2.07 ± 0.36	96	0.038 ± 0.03	0.045 ± 0.002	118	–	–	–
Mn/μg g^{-1}	519 ± 18	498 ± 9	96	28.4 ± 1.9	27.8 ± 0.1	98	9.8 ± 0.2	9.5 ± 0.1	97
Ni/μg g^{-1}	40 ± 2	37 ± 1	93	–	–	–	–	–	–
Pb/μg g^{-1}	73 ± 2	72 ± 0.6	99	–	–	–	0.75 ± 0.05	0.81 ± 0.01	108

[a] $n = 3$.
[b] No certificated value.

pH values of soil samples in this site ranged from 4.93 to 5.66, which corresponded to Grade II of the Environmental quality standard for soils (GB15618-1995). As shown in Table 3, the GM of 10 metal elements (As, Ba, Cd, Co, Cr, Cu, Hg, Mn, Ni and Pb) were 4.07, 3.03, 1.19, 1.13, 6.12, 9.88,0.33, 344.72, 34.65 and 55.81 μg g^{-1}, respectively. Cd, Cr, Cu, Hg, Ni and Pb exceeded the corresponding background values by 8.4, 1.1, 4.7, 2.3, 1.3 and 1.9-folds, respectively. In addition, Cd, Cu and Hg exceeded the MAC levels (0.20, 50.00, 0.20 μg g^{-1}, respectively) by 4.0, 2.0 and 1.1-folds, respectively. The concentrations of Cd in soil samples were in the range of 0.55–7.86 μg g^{-1}. This might indicate that point source pollutions existed in the sampling area. These results showed that the soil in this region was primarily contaminated by Cd, followed by Cu, whereas Hg pollution was not serious. Levels of Pb, Ni and Cr exceeded the corresponding background value, but they were under the maximum allowable concentrations, indicating no serious contamination of these metals in this area.

3.2. Heavy metal concentrations in polished rice and hull

3.2.1. Comparison of heavy metals in polished rice and hull

Though only the inner rice part, so-called polished rice, is consumed by human, the hull part is usually consumed by livestock. Hazardous elements may also accumulate in human body through the food chain by consumption of these livestock. Ten heavy metals in polished rice and hull samples collected from the E-waste recycling area were determined. The results were shown in Fig. 1. In the layout, the horizontal line in the box represents the median value and the vertical bars display the range of the data. The concentrations of metals other than As, Cd and Hg in polished rice were significantly different from those in the hull ($p < 0.05$) (Fig. 1a). Generally, the metal concentrations in hull were higher than those in the polished rice (Fig. 1b). The concentrations of Ba, Cu, Mn, Ni and Pb in the hull were 1.9, 3.4, 8.4, 11.6 and 6.3-folds higher than those in the polished rice. Moreover, metals in polished rice and hull had low correlation with those in the soil samples, which differed from previous results (Cao and Hu, 2000). It suggests that in this area, the accumulation of metals in the hull might partly come from aerial deposition. In this study, we found that Cr level in hull exceeded that in polished rice by as much as 253.7-folds. In a survey of the heavy metal compositions in total suspended particles (TSP) in Guiyu, another E-waste recycling area, Deng et al. (2006) found that the most enriched metals were Cr, Zn, Pb and Cu, and the occurrence of metals generally ranked in the order Cr > Zn > Pb > Cu > Mn > Cd > Ni > As. This result partly confirms our deduction that aerial deposition contributed to higher contents of Cr, Pb, Mn and Cu in hull than in polished rice. The concentration of Co in rice was 1.7-fold higher than that in hull (Fig. 1c). Among the 10 elements analyzed, Cd, Mn and Hg concentrations in polished rice were significantly correlated with those in hull ($R^2 = 0.867$, 0.629 and 0.845, respectively).

Table 3
Comparison of total heavy metals contents in soil in Taizhou with background values and national MAC (μg g^{-1})

	As	Ba	Cd	Co	Cr	Cu	Hg	Mn	Ni	Pb
TSO-01	3.22	340.13	0.79	12.54	71.26	111.78	0.30	362.95	41.57	54.41
TSO-02	5.58	301.43	0.65	9.91	55.92	83.80	0.76	391.78	27.63	64.56
TSO-03	3.91	350.00	7.02	13.77	74.12	183.97	0.24	358.97	52.67	51.98
TSO-04	3.05	292.41	0.61	10.06	54.41	56.07	0.30	294.39	25.83	54.69
TSO-05	4.61	285.26	7.86	10.98	63.38	236.89	0.35	239.72	46.19	51.96
TSO-06	4.60	295.09	0.55	10.76	59.95	108.06	0.37	438.64	30.43	58.20
GM	4.07	303.26	1.19	11.26	61.21	98.81	0.33	344.72	34.65	55.81
Background	5.87	–[a]	0.14	12.67	57.96	20.85	0.14	383.60	26.43	29.76
MAC	30.00	–	0.30	–	250.00	50.00	0.30	–	40.00	250.00

[a] No relevant data.

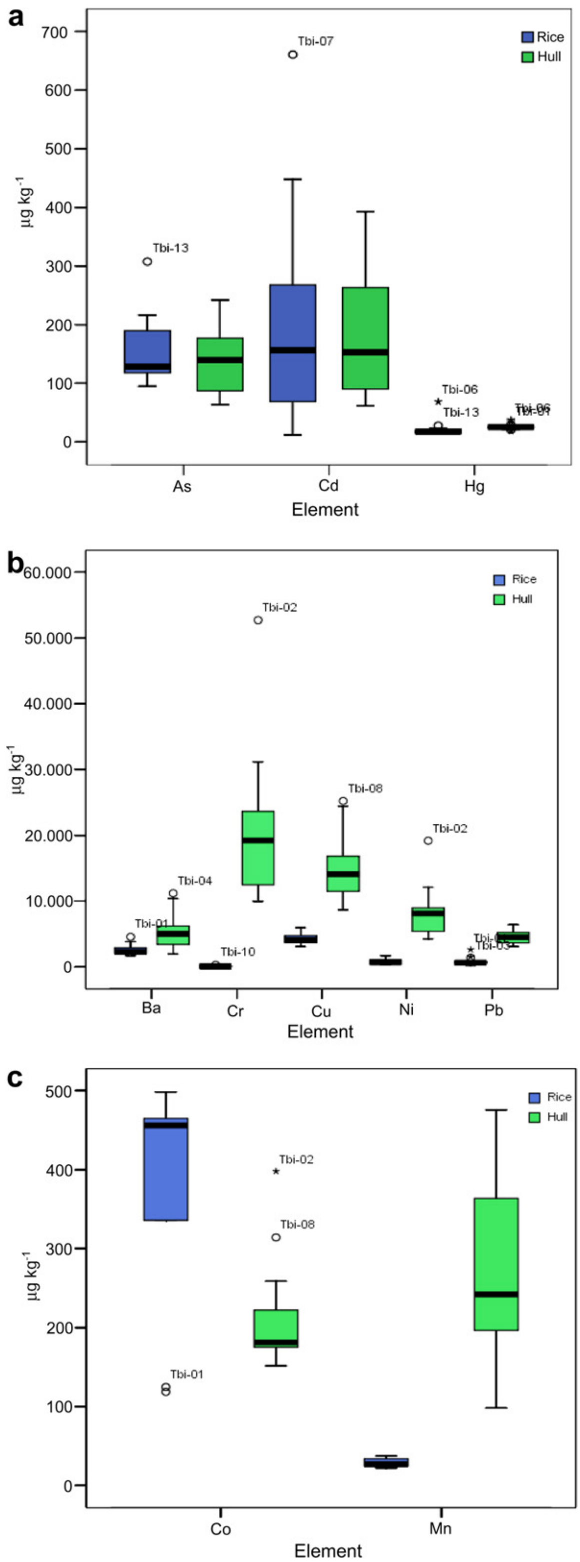

Fig. 1. (a) Box-and-whisker plots of As, Cd and Hg contents in polished rice and hull which were not significantly different (µg kg^{-1}) ($p > 0.05$). (b) Box-and-whisker plots of Ba, Cr, Cu, Ni and Pb concentration in polished rice and hull which were significant different (µg kg^{-1}) ($p < 0.05$). (c) Box-and-whisker plots of Co and Mn concentrations in polished rice and hull. The Co concentration in polished rice was higher than in hull (µg kg^{-1}). Mn concentration in polished rice and hull was calculated in µg g^{-1}. In the layout, the horizontal line in the box represents the median and the vertical bars display the range of the data.

3.2.2. Comparison with national standards and other studies

Generally, GM illustrates more exact distribution of the element concentrations in rice samples, but comparison with many other studies is difficult due to the lack of information on GM. Of all the contaminated polished rice samples we measured, the highest concentrations of Pb, Cd, As, Hg were found to be 2.60, 0.66, 0.22 and 0.07 µg g^{-1} respectively. Comparatively, the concentrations of toxic elements, such as Cd, Ba and Pb, in rice collected from Taizhou are apparently higher than those from other areas. The GM concentration of Ba reached 2.47 µg g^{-1}, which was approximately five times higher than the four control samples employed in this study. Moreover, the maximum concentration of Ba in four commercial rice samples was even lower than the minimum concentration in the Taizhou samples (Table 4). Further, the Cd and Pb concentrations in Taizhou rice were approximately 8-fold and 4-fold greater than those found in rice from other areas. The concentrations of other toxic elements (As, Hg, Cu and Cr) in Taizhou rice fall within the range of previous studies. According to the national standard for safety milled rice criteria (NY5115-2002), the maximum allowable concentrations (MAC) of As, Cd, Pb and Hg are 0.50, 0.20, 0.20 and 0.02 µg g^{-1}, respectively. In this study, the Cd, Pb, and Hg contents in 31%, 100%, and 15.3% of the rice samples from Taizhou exceeded the national standards. The GM of Pb for the 13 samples was 0.69 µg g^{-1}, which exceeded the MAC (0.20 µg g^{-1}) by 3.5-folds. The GM of Cd did not exceed the MAC (0.20 µg g^{-1}), but arithmetic mean (0.23 µg g^{-1}) slightly exceeded the limit. Table 4 shows detailed results for the heavy metal contents in the rice samples were summarized and compared with those found in some previous studies. These results indicated that rice from Taizhou was most seriously polluted by Pb, followed by Cd and Ba. It has been reported that E-waste contains abundant Pb, Ba and Cd, but their recycling efficiencies were only 5%, 0% and 0%, respectively (Puckett and Smith, 2002). The erosion of these metals from E-waste recycling activities could be discharged into the peripheral environment, thus it should not be a surprise that rice from this area was seriously contaminated with these elements.

3.3. Human exposure to metals through rice

Local inhabitants who consume rice grown in this area are exposed to heavy metal contamination. The comparison of EDI with TDI for four elements; As, Cd, Hg and Pb, are shown in Table 5.

We assumed that the local population consumes the local rice, and the EDI that was calculated from Eq. (1) is based on heavy metal levels from the rice samples. The EDI of Cd by the local population was calculated to 0.7 µg day^{-1} kg^{-1} bw, which corresponds to 70% of the TDI (1 µg day^{-1} kg^{-1} bw). The maximum daily intake of Cd from rice was 3.6 µg day^{-1} kg^{-1} bw (calculated from the maximum concentrations of Cd in rice) in Taizhou, which was 3.6-fold higher than TDI. On the other hand,

Table 4
Comparison of the mean and range concentrations (ng/g) of the studied rice sample with data available from some previous studies

Element	Area	N	AM (a)	ASD (b)	GM (c)	GSD (d)	Min	Max
As	Taizhou	13	154.7	58.5	146.6	1.4	94.7	307.6
	Commercial rice, China	4	69.5	34.9	64.3	1.5	46.9	121.5
	Vietnam (e)	31	208	–	–	–	32	465
	Bangladesh (f)	4	11.3	7.6	–	–	<5	20.2
Ba	Taizhou	13	2586.8	875.0	2472.1	1.4	1662.6	4535.5
	Commercial rice in China	4	715.7	562.5	526.2	2.6	161.6	1395.2
Cd	Taizhou	13	224.0	195.6	125.2	3.3	11.7	660.7
	Commercial rice in China	4	34.5	34.5	17.3	4.6	3.6	69.7
	Hangzhou (g)	5	31.8	36.7	17.2	3.6	trace	92
Cu	Taizhou	13	4259.9	825.7	4189.1	1.2	3036.6	5184.1
	Commercial rice in China	4	3325.9	773.9	3266.3	1.2	2811.9	4477.9
	Vietnam (e)	31	2600	–	–	–	1100	5800
Pb	Taizhou	13	2042.2	2069.7	690.4	1.8	256.3	2601.7
	Commercial rice in China	4	355.5	266.8	333.9	1.8	166.7	745.4
	Hangzhou (g)	5	131.2	102.6	106.6	2.01	45	308
Ni	Taizhou	13	761.3	391.3	676.1	1.7	339.4	1134.4
	Commercial rice in China	4	475.8	276.2	413.9	1.9	201.4	818.4
	Vietnam (e)	31	869	–	–	–	<100	2022
	Australia (e)	11	134	–	–	–	<100	204
Mn	Taizhou	13	28639.9	5570.3	28157.2	1.2	21977.0	37489.7
	Commercial rice in China	4	9363.1	3288.1	8908.9	1.4	5804.3	12707.5
	Vietnam (e)	31	9900	–	–	–	5900	16300
Hg	Taizhou	13	22.0	14.5	19.7	1.5	15.6	68.4
	Commercial rice in China	4	28.8	5.6	28.4	1.2	24.4	36.4
Cr	Taizhou	13	106.8	83.2	75.3	2.7	6.0	279.4
	Commercial rice in China	4	199.3	157.1	158.3	2.2	62.0	424.4
Co	Taizhou	13	386.9	131.5	354.4	1.6	118.6	498.3
	Commercial rice in China	4	169.4	169.7	121.7	2.5	55.0	419.5

a, arithmetic means; b, arithmetic standard deviations; c, geometric means; d, geometric standard deviations; e, Phuong et al. (1999); f, Rmalli et al. (2005); g, Cheng et al. (2006); others obtained in this study.

some individuals in this area may consume more than twice of the average amount of rice, and their daily dietary intakes of Cd would further exceed the TDI. Chronic Cd poisoning due to rice-mediated environmental exposure induced the Itai-itai disease in Japan in 1960s. The disease, which is characterized by osteomalacia with simultaneous renal dysfunction, has been well documented. Though the Cd concentration in Taizhou rice was slightly lower than that in Japan (Nogawa et al., 2004), attention still needs to be paid. The TDI for Pb was set by the JECFA (WHO, 1993) at 3.6 μg day^{-1} kg^{-1} bw. The dietary intakes for the local population ranged from 1.4 to 14.0 μg day^{-1} kg^{-1} bw with a mean value at 3.7 μg day^{-1} kg^{-1} bw. Five out of 13 samples (38.5%) exceed the TDI. Moreover, the EDI here was only evaluated for Cd and Pb in rice, which accounts for only a fraction of the contamination through daily dietary consumption. If taking the whole contamination through dietary into consideration, the Cd and Pb dietary exposure for the local population in this area would probably reach unsound levels. Huo et al. (2007) have recently reported elevated Pb levels in blood samples from children in Guiyu, another E-waste recycling center in China. Our metal analysis results suggest that this phenomenon may recur in Taizhou partly due to the heavy contamination of Pb in rice, though this needs further study. As a result, daily intake of rice or crops grown in this area might cause detrimental health hazards to the consumers.

Table 5
Mean estimated daily intake by a 60 kg body weight person and the range in Taizhou

Element	TDI	MEDI	%TDI	% E-TDI	MinI	MaxI
As	50.0	0.8	1.6	0.0	0.5	1.7
Cd	1.0	0.7	67.4	38.5	0.1	3.6
Hg	0.7	0.1	14.7	0.0	0.1	0.4
Pb	3.6	3.7	103.2	38.5	1.4	14.0

TDI: tolerable daily intake (μg day^{-1} kg^{-1} bw).
MEDI: mean (GM) estimated daily intake (μg day^{-1} kg^{-1} bw).
MinI: estimated minimum daily intake (μg day^{-1} kg^{-1} bw).
MaxI: estimated maximum daily intake (μg day^{-1} kg^{-1} bw).
%E-TDI: represents the percentage of heavy metal in rice samples which exceed the TDI.

4. Conclusion

From the results of the rice and soil samples gathered from this study, we obtained a better knowledge regarding the impact of E-waste recycling activities on the environment and the potential risk to human health. Based on the data obtained to date, the agricultural soil in Taizhou was most severely contaminated by Cd, followed by Cu and Hg. The levels of Pb, Ni and Cr exceeded the corresponding background values, but were below the national MAC, implicating no serious contamination of these elements in this area. Low correlations among the polished rice, hull and soil and the high metal contents detected in hull suggested that aerial deposition is a potential source for metal contamination in rice. In regards to the national food safety criteria, Pb content in all rice samples exceeded the national MAC. By estimating the daily intake of Pb by the local inhabitants, we concluded that the Pb daily intake in this area might exceed the TDI recommended by FAO. Cd content in rice from this area was much higher than those from other areas and those of previous studies, which further imply that high Cd contamination exists in E-wastes recycling areas. Although the mean estimated daily intake of Cd from rice is 70% of the TDI, it still holds a high proportion of TDI, suggesting local rice consumption may induce excessive Cd intake as well. Also, both As and Hg contamination through rice should not be neglected, though their mean EDIs were lower than TDI. However, the consumption of rice accompanying with other local contaminated foods such as meat, milk, and crop will probably contribute to elevated levels of both metals. As a whole, long term consumption of the local rice may bear high risk of heavy metal exposure to the consumer. This caution should not only concern the local residents around the E-waste center but also extend to people living in downstream or downwind of this area. Moreover, a great deal of attention should also be paid regarding the contamination of biota through the food chain. Relevant data are still limited and further studies need to be conducted.

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