Heavy metals concentrations of surface dust from e-waste recycling and its human health implications in southeast China

ANNA O. W. LEUNG [a], NURDAN S. DUZGOREN-AYDIN [b], K.C. CHEUNG [a] AND MING H. WONG[a,*]

[a] *Croucher Institute for Environmental Sciences, and Department of Biology, Hong Kong Baptist University, Hong Kong, PR China*

[b,1] *Department of Earth Sciences, University of Hong Kong, Hong Kong, PR China*

*Correspondence author phone: +852-3411-7746; fax: +852-3411-7743; e-mail: mhwong@hkbu.edu.hk

[1]Present address: National Center for Natural Products Research, The University of Mississippi, 38677 MS, USA

SUPPORTING INFORMATION

TABLE S1. Soil guidelines (mg/kg) (<2 mm)

TABLE S2. Comparison of heavy metal concentrations (mg/kg) in street/road, park, school and house dust according to dust particle size

TABLE S3. Estimated hazard quotients and hazard indices for heavy metals via dust ingestion exposure

TABLE S1. Soil guidelines (mg/kg) (<2 mm)

Guidelines	Cd	Co	Cr	Cu	Ni	Pb	Zn
The New Dutch List[a] (The Netherlands)							
Optimum value	0.8	20	100	36	35	85	140
Action value	12	240	380	190	210	530	720
EQS[b] (China)							
Grade I (natural background)	0.2	-	90	35	40	35	100
Grade II (agricultural and related use)	0.3	-	200	100	50	300	250
Grade III (industrial activity)	1	-	300	400	200	500	500
CEQG[c] (Canada)							
Agricultural	1.4	40	64	63	50	70	-
Residential/park	10	50	64	63	50	140	-
Industrial	22	300	87	91	50	260	-

[a](*1*)
[b](*2*)
[c](*3*)

TABLE S2. Comparison of heavy metal concentrations (mg/kg) in street/road, park, school and house dust according to dust particle size

Particle size (μm)	Type	City, Country	Cd	Co	Cr	Cu	Ni	Pb	Zn	Reference
<2000	urban roads	Hong Kong, China						327±54 (232-411)		1
<2000	rural (no traffic)	Hong Kong, China						164		1
<2000	car park	Hong Kong, China						304±4 (301-308)		1
<2000	tunnel ceiling	Hong Kong, China						668±496 (375-1410)		1
<2000	streets around urban parks	Hong Kong, China	3.77±2.25			173±190		181±92.9	1450±869	2
<2000	urban roads	Guangzhou, China				193±195 (34-669)		255±220 (75-926)	586±487 (211-1826)	3
<2000	residential/industrial Zn smelter	Avilés, Spain	22.3±1.42# (9.60-104)	7.03±1.15# (5-11.5)	41.6±1.09# (32-54.5)	183±1.24# (104-374)	27.5±1.16# (18-50)	514±1.21# (330-964)	4892±1.42# (2422-23400)	4
<2000	major streets, industrial sites	Coventry, UK	4.1* (ND-2600)			65.8* (ND-100500)	55.9* (ND-1803)	40* (ND-3300)	65.4* (ND-4556)	5
<2000	urban road	Seoul, Republic of Korea	3			101		245	296	6
<1000	7 playgrounds	Hong Kong, China	2.63 (1.3-4.2)			201 (5.3-557)		302 (85-692)	1517 (333-3357)	7
<1000	urban roads	Xian, China			167±196 (28-853)	95.0±138 (20-1071)		231±431 (29-3060)	421±456 (80-2112)	9
<1000	road	7 London boroughs, UK	4.2# (<1-280)			115# (18-2400)		1354# (172-9660)	513# (121-5150)	9
<1000	playgrounds	7 London boroughs, UK	2.4# (<1-12)			9# (16-712)		430# (93-6860)	620# (134-3740)	9
<1000	house	7 London boroughs, UK	7.6# (<1-336)			208# (9-5300)		1010# (5-36900)	1090# (81-115000)	9
<1000	road	Britain mining villages, UK	41.3# (4-252)			639# (200-3180)		2160# (1190-4620)	-	9
<1000	playgrounds	Britain mining villages, UK	-			170# (53-364)		4390# (1190-13400)	-	9

<1000	house	Britain mining villages, UK	2.7 (<1-373)		562 (99-8000)		1870[#] (606-7020)	2100 (624-8200)	9
<750	road curbs of urban parks	Hong Kong			297 (50-741)		347 (107-915)	2582 (534-6584)	10
<600	rural major road	Lancaster, UK	2.78		199		2540	458	11
<600	urban major road	London, UK	2.68		108		2100	539	11
<600	rural road (dry)	Lancaster, UK	3.29		312		1570	496	11
<600	urban major road	Lancaster, UK	3.66		75		1090	260	11
<600	open car park	Lancaster, UK	4.91		71		939	440	11
<600	rural road (wet)	Lancaster, UK	3.15		114		660	372	11
<500	roadside	London, UK	2.87±1.84 (1.0-7.3)		158±166 (48-563)	29.7±22.1 (16-106)	715±373 (160-2060)	453±249 (65-1150)	12
<500	Borough-wide survey roadside Borough sample area	London, UK	-		612±4076 (16-43470)	41±55.6 (49-443)	741±1899 (56-20535)	548±1288 (48-13740)	12
<500	playground dust	London, UK					779±844.3 (46-3420)		12
<500	classroom dust	London, UK					703±1073.5 (30-5357)		12
<500	household dust	London, UK					363±218.9 (43-771)		12
<500	industrial	Delhi, India	~17[+]	~9000[+]	~1300[+]	~980[+]	~150[+]	~360[+]	13
<500	urban major road	Delhi, India	~15.5[+]	~500[+]	~210[+]	~130[+]	~200[+]	~315[+]	13
<500	rural road	Delhi, India	~13[+]	<200[+]	<20[+]	~90[+]	~125[+]	~120[+]	13
250-500	road	Hong Kong, China			384.73		379.43	1732	14
250-500	car park	Hong Kong, China			132.27		208	576	14
250-500	road	London, UK			284.88		831.00	1281.00	14
250-500	car park	London, UK			233.80		767.00	1664.00	14
<250	urban parks/open spaces	Hong Kong, China	3.3±2.1		138.8±92.8		248±166	1998±1650	15
<250	roadside	Hong Kong, China	14.3±35.7		618±2118		2558±209	2607±1813	15
<250	households	Hong Kong, China	17.6±37.6 (0.2-2341)		976±3116 (46.0-32611)		219±216 (0.1-1415)	1975±1860 (71.8-12940)	16
<250	nursery schools/kindergartens (interior dust)	Hong Kong, China	8.48±20.6 (0.61-150)		247±212 (45.1-1052)		200±145 (3.11-783)	2294±1075 (472-6867)	17

<250	(exterior dust)	Hong Kong, China	4.07±5.01 (0.75-25.3)			409±561 (66.7-2996)		280±309 (48.8-2108)	2694±1872 (898-9900)	17
<250	homes	Hong Kong, China	17.63			981		220	2005	17
<250	62 urban playgrounds/parks	Hong Kong, China	7.0±1.9 (4.6-13.7)		263±408 (11.8-2681)	143±109 (17.0-859)		77.3±39.4 (1.8-263)	1883±1309 (159-6658)	18
125-250	road	Hong Kong, China				239		527	2065	14
125-250	car park	Hong Kong, China				112		216	623	14
125-250	road	London, UK				292.00		1029.00	1924	14
125-250	car park	London, UK				111.00		544.00	987	14
<170	Industrial/commercial residential roadsides, carparks, playgrounds, flyovers, bus terminals, windows, walls, floors of buildings	Hong Kong, China	7.6±8.6 (0-58.4)			635±829 (2-5606)		1287±1194 (134-16800)	2902±4807 (170-63500)	19
<106	roadside	Hong Kong, China						1627		20
0-125	road	Hong Kong, China				392		755	2397	14
0-125	car park	Hong Kong, China				92.1		230	574	14
0-125	road	London, UK				512.00		1637.00	13	14
0-125	car park	London, UK				216.00		1107.00	13	14
<63	printed circuit board workshops	Guiyu, China	55.3±46.7 (11.0-104)	21.3±3.51 (18-25)	108.3±33.3 (83-146)	13400±10900 (4100-25400)	605±374 (292-1020)	52770±22400 (31300-76000)	5080±3580 (2340-9130)	21
<63	house interior	Gujranwala, Pakistan	13.3 (1.6-92)			64 (35-440)		188 (71-477)	241 (110-511)	22
<63	street dust outside house		3.1			42		113	133	22
<37	urban road	Hsinchu, Taiwan	1.2±0.5		130±19	123±54	64±15	263±49	503±70	23
<37	electrical industrial district	Hsinchu, Taiwan	2.2±0.9		200±59	101±24	54±11	204±29	493±69	
<37	tunnel	Hsinchu, Taiwan	-		174±75	163±35	87±30	220±51	1290±350	

( )Range

*Median

#Geometric mean

+Estimated from the bar graphs of Figure 2 (pg. 98) of Ref 13.

TABLE S3. Estimated hazard quotients and hazard indices for heavy metals via dust ingestion exposure

	HQ							HI (Average conc.)	HI (Maximum conc.)
	Cd	Co	Cr	Cu	Ni	Pb	Zn		
Adult									
PCBRW	0.043	0.0018	0.039	0.33	0.12	50.2	0.024	50.8	96.5
Street B-1	0.022	0.0015	0.023	0.25	0.024	10.3	0.013	10.6	62.7
Street B-2	0.0090	0.00058	0.0072	0.029	0.0071	0.450	0.0028	0.51	1.18
Food market	0.0067	0.00051	0.015	0.014	0.015	0.630	0.0033	0.68	1.73
Street L	0.012	0.00089	0.035	0.066	0.0082	0.103	0.0025	0.23	0.82
Street G	0.0068	0.00033	0.0069	0.0023	0.0019	0.031	0.0029	0.052	0.223
SU	0.0076	0.00072	0.0092	0.0016	0.0015	0.028	0.0010	0.049	0.070
Child									
PCBRW	0.34	0.014	0.31	2.67	0.96	402	0.19	406	772
Street B-1	0.18	0.012	0.18	1.97	0.19	82.6	0.10	85.2	502
Street B-2	0.072	0.0046	0.058	0.23	0.057	3.60	0.023	4.05	9.61
Schoolyard	0.069	0.0041	0.16	0.15	0.032	2.31	0.028	2.75	4.32
Street L	0.097	0.0072	0.28	0.52	0.065	0.83	0.020	1.82	6.73
Street G	0.054	0.0027	0.055	0.019	0.016	0.25	0.023	0.42	1.93
SU	0.061	0.0057	0.073	0.013	0.012	0.22	0.0083	0.40	0.70

PCBRW: printed circuit board recycling workshop

Oral RfD (mg/kg/day): Cd, 0.001; Cd, 0.02; Cr, 0.003; Cu, 0.04; Ni, 0.02; Pb, 0.0035; Zn, 0.3 (*1*)

Qualitative descriptions for noncancer toxic health risks: HQ≤1 (minimal), >1-5 (low), >5-10 (moderate), >10 (high) (*2*)

Literature Cited on Table S1

(1) VROM. The New Dutch List. Intervention values and target values: Soil quality standards; Netherlands Ministry of Housing, Spatial Planning and Environment, Department of Soil Protection: The Hague, Netherlands, **2001**.

(2) SEPA (State Environmental Protection Administration). Environmental Quality Standards for Soils (GB 15618-1995), **1995**.

(3) CCME (Canadian Council of Ministers of the Environment). Canadian Environmental Quality Guidelines, Summary Table, December **2003**.

Literature Cited on Table S2

(1) Duzgoren-Aydin, N.S.; Li, X.D.; Wong, S.C. Lead contamination and isotope signatures in the urban environment of Hong Kong. *Environ. Int.* **2004**, *20*, 209-217.

(2) Li, X.D.; Poon, C.S.; Liu, P.S. Heavy metal contamination of urban soils and street dusts in Hong Kong. *Appl. Geochem.* **2001**, *16*, 1361-1368.

(3) Duzgoren-Aydin, N.S.; Wong, C.S.C.; Song, Z.G.; Aydin, A.; Li, X.D. Fate of heavy metal contaminants in road dusts and gully sediments in Guangzhou, SE China: a chemical and mineralogical assessment. *Hum. Ecol. Risk Assess.* **2006**, *12*, 374-389.

(4) Ordóñez, A.; Loredo, J.; De Miguel, E.; Charlesworth, S. Distribution of heavy metals in the street dusts and soils of an industrial city in northern Spain. *Arch. Environ. Contam. Toxicol.* **2003**, *44*, 160-170.

(5) Charlesworth, S.M.; Lees, J.A. The distribution of heavy metals in deposited urban dusts and sediments, Coventry, England. *Environ. Geochem. Health* **1999**, *21*, 97-115.

(6) Chon, H.T.; Kim, K.W.; Kim, J.Y. Metal contamination of soils and dusts in Seoul metropolitan, Korea. *Environ. Geochem. Health* **1995**, *17*, 139-146.

(7) Wong, J.W.C.; Mak, N.K. Heavy metal pollution in children playgrounds in Hong Kong and its health implications. *Environ. Technol.* **1997**, *18*, 109-115.

(8) Han, Y.M.; Du, P.X.; Cao, J.J.; Posmentier, E.S. Multivariate analysis of heavy metal contamination in urban dusts of Xi'an, Central China. *Sci. Total Environ.* **2006**, *355*, 176-186.

(9) Culbard, E.B.; Thornton, I.; Watt, J.; Wheatley, M.; Moorcroft, S.; Thompson, M. Metal contamination in British urban dusts and soils. *J. Environ. Qual.* **1988**, *17*, 226-234.

(10) Tam, N.F.Y.; Liu, W.K.; Wong, M.H.; Wong, Y.S. Heavy metal pollution in roadside urban parks and gardens in Hong Kong. *Sci. Total Environ.* **1987**, *59*, 325-328.

(11) Harrison, R.M.; Laxen, D.P.H.; Wilson, S.J. Chemical associations of lead, cadmium, copper, and zinc in street dust and roadside soil. *Environ. Sci. Technol.* **1981**, *15*, 1378-1383.

(12) Harrop, D.O.; Mumby, K.; Pepper, B.; Nolan, J. Heavy metal levels in the near vicinity to roads in a north London borough. *Sci .Total Environ.* **1990**, *93*, 543-546.

(13) Banerjee, A.D.K. Heavy metal levels and solid phase speciation in street dusts of Delhi, India. *Environ. Pollut.* **2003**, *123*, 95-105.

(14) Wang, W.H.; Wong, M.H.; Leharne, S.; Fisher, B. Fractionation and biotoxicity of heavy metals in urban dusts collected from Hong Kong and London. *Environ. Geochem. Health* **1998**, *20*, 185-198.

(15) Lam, K.C.; Ng, S.L.; Hui, W.C.; Chan, P.K. Environmental quality of urban parks and open spaces in Hong Kong. *Environ. Monit. Assess.* **2005**, *111*, 55-73.

(16) Tong, S.T.Y.; Lam, K.C. Home sweet home? A case study of household dust contamination in Hong Kong. *Sci .Total Environ.* **2000**, *256*, 115-123.

(17) Tong, S.T.Y.; Lam, K.C. Are nursery schools and kindergartens safe for our kids? The Hong Kong study. *Sci. Total Environ.* **1998**, *216*, 217-225.

(18) Ng, S.L.; Chan, L.S.; Lam, K.C.; Chan, W.K. Heavy metal contents and magnetic properties of playground dust in Hong Kong. *Environ. Monit. Assess.* **2003**, *89*, 221–232.

(19) Yim, W.W.S.; Nau, P.S. Distribution of lead, zinc, copper and cadmium in dust from selected urban areas of Hong Kong. Hong Kong Engineer January. **1987,** 7-14.

(20) Lau, W.H.; Wong, M.H. An ecological survey of lead contents in roadside dusts and soils in Hong Kong. *Environ. Res.* **1982**, *28*, 39-54.

(21) Brigden, K.; Labunska, I.; Santillo, D.; Allsopp, M. Recycling of electronic wastes in China and India: Workplace and environmental contamination. Technical Note: 09/2005 (Section 1). Greenpeace Research Laboratories, Department of Biological Sciences, University of Exeter, Exeter EX4 4PS, UK. **2005**. Greenpeace International.

(22) Jabeen, N.; Ahmed, S.; Hassan, S.T.; Alam, N.M. Levels and sources of heavy metals in house dust. *J. Radioanal. Nucl. Chem.* **2001**, *47*, 145-149.

(23) Wang, C.F.; Chang, C.Y.; Tsai, S.F. Characteristics of road dust from different sampling sites in northern Taiwan. *J. Air Waste Manage. Assoc.* **2005,** *55*, 1236-1244.

Literature Cited on Table S3

(1) US EPA, Integrated Risk Information System (IRIS), http://www.epa.gov/iris/

(2) ATSDR (New York State Department of Health under cooperative agreement with the Agency for Toxic Substances and Disease Registry). Public Health Assessment. Johnstown City Landfill, Johnstown, Fulton Country, New York. CERCLIS NO. NYD980506927. **1995**, www.atsdr.cdc.gov/HAC/PHA/johnstow/jcl_toc.html.