

Pollutants in Hong Kong Soils: As, Cd, Cr, Cu, Hg, Pb and Zn

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46 Abstract

47 Six heavy metals (Hg, Cu, Cd, Cr, Pb, Zn) and 1 metalloid (As) in surface soils of Hong
48 Kong were investigated in 10 land use categories (urban park, greening area, country
49 park, rural area, restored landfill, agricultural farmland, orchard farm, crematorium,
50 industrial and near highway area). Edaphic Hg concentration in Hong Kong was firstly
51 reported here. Clustering of land uses was observed based on total pollutants
52 concentrations (sum of 7 metals). The most polluted cluster consisted of industrial and
53 highway areas (median: 617 to 833 mg kg⁻¹) and the runner-up cluster included urban
54 park, greening area and restored landfill (median: 400 to 500 mg kg⁻¹). However, this
55 general finding was not observed for Hg, where higher concentration was found in
56 agricultural farmland (median 109 µg kg⁻¹). The use of low quality fertilizers, together
57 with the contribution from exhausts and wearable parts from automobiles were believed
58 to be the major sources of Cr, Cu and Zn in Hong Kong, while the application of Hg-
59 containing agrochemicals maybe the main mechanism of Hg contamination in
60 agricultural soil. Based on the daily intake assumption of 0.2 g d⁻¹ of soil particles by
61 USEPA, direct ingestion of Hg-containing soils is not a major exposure pathway for
62 population in Hong Kong. When comparing the edaphic heavy metal concentrations
63 with Dutch soil quality guidelines demonstrated that Hg, Cd and Pb were not in level
64 of health concerns, while Cu, Cr and Zn in less than 6% of total samples were found to
65 exceed the Dutch intervention values sporadically. In contrast, suburban soils from
66 northern and northeastern Hong Kong were mostly contaminated with As (10% of total
67 samples) at concentration that could be potentially causing adverse health impacts to
68 the nearby population.

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73 Keywords: Urban soils, South China, Heavy Metals, Contamination, Pollution

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75 **1. Introduction**

76 Environmental contamination of heavy metals has been reported world-wide, and
77 excessive exposure to toxic metals has been commonly known to be hazardous to
78 human health (Agency for Toxic Substances and Disease Registry, 2006). Among
79 these toxic metals, Hg is of particular concern as it is characterized by high vapour
80 pressure. This unique feature makes it ubiquitous in the environment and become a
81 global pollutant. In addition, its toxicity to human, especially childbearing women, also
82 highlighted the concern from government agency to work on Hg reduction (Srivastava
83 *et al.*, 2006). In countries under the European Union, Hg is classified as a dangerous
84 chemical because of its mobility, volatility and its bioaccumulative properties within
85 organisms and along the food chains (Mukherjee *et al.*, 2004).

86

87 A recent review on Hg contamination in China (Zhang and Wong, 2006) revealed that
88 soil Hg contents in most cities (70 to 700 $\mu\text{g kg}^{-1}$, 12 out of 14 cities reviewed) exceeded
89 the background edaphic Hg value in China (65 $\mu\text{g kg}^{-1}$) (State Environmental Protection
90 Administration of China, 1990). Enrichment of Hg and other metals was observed in
91 agricultural crop soils (Wong *et al.*, 2002) and sediments (Cheung *et al.*, 2003) around
92 the Pearl River Delta. This led to higher concentrations of all the toxic metals found in
93 bivalves and freshwater fish collected (including from the field and available in
94 markets) within the region (Fang *et al.*, 2001, 2003; Kong *et al.*, 2005; Zhou and Wong,
95 2000), including seafood in Hong Kong (Tam and Mok, 1991).

96

97 In Hong Kong, it has been observed that Hg was bioaccumulated in cetaceans and Indo-
98 Pacific hump-backed dolphins (*Sousa chinensis*) (Parsons, 1998, 1999). It was noted
99 that the mean value of Hg in adult human hair was 3.3 $\mu\text{g g}^{-1}$ which was higher the

100 mean value for US counterpart (1.5 $\mu\text{g g}^{-1}$) (Dickman and Leung, 1998), also the
101 recommended limit for Hg in hair set by USEPA is 1 $\mu\text{g g}^{-1}$ (Gallagher, 2006). It was
102 indicated that the elevated Hg levels were linked to subfertility in Hong Kong males
103 (Dickman *et al.*, 1998). In addition, higher Hg levels in blood and hair of children in
104 Hong Kong were also observed to be correlated with the frequency of fish consumption
105 (Ip *et al.*, 2004).

106

107 Soils can act as both sinks, via dry atmospheric deposition; as well sources of toxic
108 metals, via re-emission of semi-volatile pollutants and wind-blown of contaminated
109 soil materials. By direct contact and inhalation of soil particles, toxic metals would
110 pose risks to human health. In addition, leaching is also one of the important pathways
111 to transfer toxic metals to water bodies and therefore accumulate in various aquatic
112 organisms. Ultimately the toxic metals can enter human via consumption of food such
113 as crops and fish, and thus understanding the levels and potential sources of toxic metals
114 are essential to secure public health. Modeling of exposure mechanisms such as dermal
115 contact and inhalation of dust of soil pollutants for risk assessment requires intensive
116 data (U.S. Environmental Protection Agency, 1996c), and there is a lack of data on
117 toxic metals especially Hg in Hong Kong soils. A more comprehensive survey of toxic
118 metals (except Hg) in Hong Kong soils was conducted almost 10 years ago (Chen *et*
119 *al.*, 1997), and therefore there seems to be a need to provide update information for all
120 the toxic metals contained in soils.

121

122 The present study was aimed to address the concerns mentioned above by providing
123 current status of heavy metal and metalloid concentrations (Hg, As, Cu, Cd, Cr, Pb and
124 Zn) in Hong Kong soils, with a special focus on Hg. To our knowledge, this is the first

125 report on edaphic Hg levels in Hong Kong and the nearby Pearl River Delta. Results
126 are valuable as they partially filled the lacking edaphic metals (especially Hg)
127 information in the Delta and can act as reference for other studies in the region where
128 contamination of Hg is in raising concern by the public. Potential sources of these toxic
129 metals are also discussed.

130

131 **2. Materials and Methods**

132 *1. Sampling and Analysis*

133 The sampling was based on 10 different land uses in Hong Kong: urban park, country
134 park, rural area, restored landfill, agricultural farmland, orchard farm, crematorium,
135 industrial area and nearby highway. All together there were 138 composite soil samples
136 that taken from the depth of 0 to 5 cm from surface by a stainless steel soil core.
137 Samples were stored in plastic bags and subsequently air-dried for 2 weeks and sieved
138 through a 2-mm mesh.

139

140 Chemical analyses of metal contents in soils were based on standard method. 0.25 g of
141 soil sample was mixed with 9 mL nitric acid, 3 mL hydrofluoric acid and 1 mL
142 hydrochloric acid and subjected to microwave-assisted acid digestion (USEPA 3052)
143 (U.S. Environmental Protection Agency, 1996a). The solutions were then filtered
144 through Advantec 5C filter paper, diluted and made up with deionized water in a 50-ml
145 plastic volumetric flask. Concentrations of As, Cu, Cd, Cr, Pb, and Zn were determined
146 by inductively coupled plasma - optical emission spectrometry (ICP-OES) (Perkin-
147 Elmer Optima 3000 DV), while Hg was quantified by Flow Injection Mercury System
148 (FIMS) (Perkin-Elmer FIMS-400) based on the cold-vapor atomic absorption
149 spectrometry (CVAA) (U.S. Environmental Protection Agency, 1996b). Limit of

150 detection (LOD) for Hg was 0.5 $\mu\text{g kg}^{-1}$, while 50 $\mu\text{g kg}^{-1}$ for Cd, Cr, Cu and Zn, and
151 100 $\mu\text{g kg}^{-1}$ for As and Pb.

152

153 *2. Quality assurance and Data analysis*

154 Standard Reference Material (SRM) 2711 was obtained from National Institute of
155 Standards and Technology (NIST, USA). An analytical blank and the SRM were
156 included in every batch of microwave acid digestion to assess the recoveries and
157 performance of extraction.

158

159 Mean individual recoveries were: $83 \pm 2\%$ (Hg), $102 \pm 5\%$ (As), $88 \pm 1\%$ (Cd), $97 \pm$
160 1% (Cu), $107 \pm 4\%$ (Pb) and $89 \pm 2\%$ (Zn). On average, the recoveries of all the
161 investigated elements in SRM were all $> 94\%$. Statistical analyses including
162 descriptive statistics, correlation analysis, and PCA analysis were conducted with
163 Statistica (version 6.0 from StatSoft). Not detected values were substituted with half
164 of lowest limit of detection (LOD) only for descriptive statistics.

165

166 **3. Results and Discussion**

167 *1. Concentration of pollutants in Hong Kong*

168 Kriged maps were constructed to show the spatial distribution of investigated pollutants
169 (Figure 1), and it is observed that most of the hotspots for pollutants were found in the
170 northern part of Hong Kong. In addition, clustering of soil pollutant concentrations in
171 land uses was also observed (Table 1). Total heavy metal concentrations were highest
172 in industrial area and area nearby highway (median 617 and 833 mg kg^{-1}); while similar
173 for urban park, greening area and restored landfill (median 400 to 500 mg kg^{-1}), and the
174 rest of the land uses are least contaminated (median 200 to 350 mg kg^{-1}). The general

175 findings that soils in industrial area and adjacent to highways were most contaminated
176 can also be observed when considering the pollutant individually, but excluding Hg.
177 Variations in pollutant concentration were usually greatest in urban park, which
178 spanned up to 3 orders of magnitude, and large variations were found in most of the
179 land uses, which reflects the heterogeneity of pollutants concentrations is under the
180 strong influence of local activities or pollution sources.

181

182 Hg concentration was ranged from non detectable (N.D.) to 3790 $\mu\text{g kg}^{-1}$, and the 10
183 most contaminated soil samples were found in urban parks, greening areas and farms
184 (29 and 3790 $\mu\text{g kg}^{-1}$). The 5 locations with highest Hg levels were: urban parks in
185 Kwun Tong (633 $\mu\text{g kg}^{-1}$), Central (985 $\mu\text{g kg}^{-1}$) and Tuen Mun (3785 $\mu\text{g kg}^{-1}$) and
186 agricultural farm in Sha Tin (762 $\mu\text{g kg}^{-1}$) and Tai Po (2196 $\mu\text{g kg}^{-1}$). The usual contents
187 of Hg in soils are in the range of 0.01 to 0.03 $\mu\text{g kg}^{-1}$ (Senesi *et al.*, 1999). For
188 contaminated areas such as Hg mine, Hg concentrations in soils were a thousand folds
189 more (Loredo *et al.*, 1999). Median Hg levels in urban soil in Korea and Norway were
190 45 and 130 $\mu\text{g kg}^{-1}$ respectively (Kim and Kim, 1999; Reimann and Caritat, 1998). The
191 mean and median Hg concentrations in Hong Kong were 135 and 70.5 $\mu\text{g kg}^{-1}$
192 respectively, which were broadly in line with the Hg concentrations observed in major
193 cities in China (Beijing: 509 $\mu\text{g kg}^{-1}$, Chongqing: 319 $\mu\text{g kg}^{-1}$, Wuhan: 314 $\mu\text{g kg}^{-1}$)
194 (Liu *et al.*, 1998; Wang, 2001; Wang *et al.*, 2005). In addition, the concentration ranges
195 of Cd (N.D. to 4.11 mg kg^{-1}), Cr (N.D. to 2500 mg kg^{-1}), and Pb (11 to 490 mg kg^{-1}) in
196 the present study (Table 1) were similar to those reported in Shenyang, Beijing, Nanjing
197 and Xi'an, China (Fang *et al.*, 2004; Wang *et al.*, 2001). However, the range of As
198 (N.D. to 336 mg kg^{-1}) was generally higher for an order of magnitude when compared
199 with those reported in major cities in China (Wang *et al.*, 2001). This implied that there

200 are significant sources of As in Hong Kong that are absent from the aforementioned
201 cities. Mean concentrations of Cu (37.2 mg kg⁻¹) and Zn (276 mg kg⁻¹) in Hong Kong
202 were closed to those found in Nanjing (Cu: 40.4 mg kg⁻¹, Zn: 280 mg kg⁻¹) (Wu *et al.*,
203 2003), but higher than those reported in Guangzhou (Cu: 9.62 mg kg⁻¹, Zn: 115.4 mg
204 kg⁻¹) (Guan *et al.*, 2001).

205

206 *2. Statistical analyses among pollutants and their potential sources*

207 The correlations among Cu, Cr and Zn were also identified by principal factor 1 (PC 1)
208 in the PCA plots shown in Figure 2a. Cadmium was excluded for PCA because of a
209 large set of not-detected value. PC 1 was able to explain 56% of the variance while PC
210 2 explained 16%. Together they extracted 72% of the total variance from the present
211 study. However, PC2 represented an antagonistic relationship between Hg and As.
212 Figure 2b shows the projection of sampling points to the factor plane. Samples from 2
213 different urban parks in New Territories contained very high level of metals (Cu, Cr
214 and Zn) and Hg. Certain agricultural farms and soils from rural and adjacent to highway
215 in the New Territories were best explained by PC2, implied that they are either high in
216 Hg or As concentration. Arsenic level was reported to be higher in industrial and heavy
217 traffic sites (Deb *et al.*, 2002), and the present study also indicated higher level of
218 edaphic As in the vicinity of highways.

219

220 Arsenic has both natural and anthropogenic sources, and their anthropogenic origins
221 included agrochemicals such as herbicides and pesticides (in form of monosodium
222 methanearsonate), and wood preservative (arsenic trioxide) (USGS, 2006). Since high
223 levels of As (>100 mg kg⁻¹) were found chiefly in soil samples collected nearby
224 highways, it is expected that automobiles could be the major contributor of As through

225 burning of fossil fuel and wearing of the As-containing babbitt bearings. Many of the
226 soil samples with As ranged from 30 to 100 mg kg⁻¹ were collected in the northern rural
227 part of Hong Kong, in which historical use of agrochemicals containing As would be
228 the main contributor of As in soils.

229

230 Higher Hg levels were observed in soils of parks and farms with plantation (Table 1).
231 Similar to As, the origin of Hg can be both anthropogenic and natural, such as ore
232 mining and forest fire. Certain fertilizers, pesticides and fungicides are known to
233 contain Hg (Matthews *et al.*, 1995; Nakagawa and Hiromoto, 1997). Therefore, the Hg
234 concentrations found in farmlands, orchard farms and urban parks maybe due to the use
235 of agrochemicals. The world-wide average of Hg content in coal is 0.1 ± 0.01 mg kg⁻¹,
236 whereas coals from southern China were enriched in Hg by 1 to 2 orders of magnitude
237 (Yudovich and Ketris, 2005). Due to the fact that Hong Kong is located at the southern
238 tip of PRD, which is known for its electrical and electronic manufacturing industry, the
239 high power demand and the associated emission of Hg is likely to create a regional Hg
240 problem (Wang *et al.*, 2006), and hence contributes to Hg level in Hong Kong soils.

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242 Higher levels of Hg in human hair leading to subfertility in males have been suspected
243 to link with higher rates of fish consumption in Hong Kong (Dickman *et al.*, 1998;
244 Dickman and Leung, 1998). The average consumption rate of seafood is about 60 kg
245 yr⁻¹ person⁻¹, which is equivalent to 167 g d⁻¹ person⁻¹, and the mean Hg levels in marine
246 and freshwater fish available in markets were 120 and 80 µg kg⁻¹ respectively (Dickman
247 and Leung, 1998). The present study showed that the average Hg level of 135 µg kg⁻¹
248 in Hong Kong soils is slightly higher than those reported in fish. However, the assumed
249 ingestion amount of soil particles for children (15 kg in weight) is 0.2 g d⁻¹ when

250 calculating the soil screening level for residential exposure of soil pollutants (U.S.
251 Environmental Protection Agency, 1996c), which is 833 folds less than the average
252 intake rate of fish (167 g d⁻¹). It is therefore believed that the direct ingestion of Hg-
253 contaminated soils is not a major health concern in Hong Kong.

254

255 Table 2 shows the most prominent correlations were Cu-Cr, Cu-Pb and Cu-Zn, which
256 were found in 5 out of 10 different land uses. Soil samples collected adjacent to
257 highway, country park, agricultural farmland, crematorium and industrial area did not
258 show more than 2 significant correlations. It is a common practice to use compost as
259 soil conditioner in urbanized areas. In Hong Kong, the sources for composting are
260 largely derived from livestock wastes from pig and poultry farms under the free
261 livestock waste collection service provided by the government. Pig manure contains
262 high levels of Cu and Zn (Bowland, 1990) as common additives in pig feed to increase
263 the feed conversion efficiency and economic returns (Jin *et al.*, 1995). Cases of
264 excessive addition of Cu and Zn in feeds were noted (Kessler *et al.*, 1994), and
265 considerable amounts of these metals were also reported in local composts (Wong,
266 1990). Apart from compost, fertilizers are also known to contain As, Cd, Cr, Pb and
267 Zn (Guan *et al.*, 2001; Renner, 2004). Land application of sewage sludge was also
268 reported to be the principle sources of heavy metals, especially Cd and As (Chu and
269 Wong, 1984; Elinder, 1985), but this possibility can be ruled out since sludge is
270 commonly dumped in domestic landfills in Hong Kong. In England and Wales soil,
271 greatest inputs of Zn and Cu were from animal manure and greatest inputs of Cr were
272 from industrial wastes (McGrath, 2000). The significant correlations of Cu-Cr, Cu-Pb
273 and Cu-Zn implied that they are derived from the same sources, and the most likely
274 source of these metals in Hong Kong soil is from low quality fertilizers, because of its

275 ease of application and more stable quality than compost. In addition, Zn and Cu are
276 pollutants associated with automobiles (Viklander, 1997). Approximately 3% of ZnO
277 is commonly added to the tyres of vehicles as a vulcanization agent and the wear of
278 tyres can be a significant source of Zn in urban areas (Friedlander, 1973). Other heavy
279 metal compounds including Cu, Cd and Pb (~0.002%, <0.001% and <0.005%
280 respectively) are identified in tyres (UNEP, 2000). Other wearable parts of vehicles
281 such as brake and brake lining also contained high contents of Cu, Pb and Zn (80 to 24
282 000 mg kg⁻¹) (Westerlund, 2001) and therefore contribute a significant portion of heavy
283 metals in soils.

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285 Lead pollution in cities was commonly recognized as one of the major pollutants caused
286 by vehicle emissions (Yang *et al.*, 2000). Hong Kong government introduced unleaded
287 petrol (ULP) in 1991 and banned the supply, sale and dispensing of leaded petrol as
288 well as any fuel additives containing Pb in 1999 (Hong Kong Environmental Protection
289 Department, 1999), resulting in a decline of Pb concentration in street dust of Hong
290 Kong from 1300 ± 1400 mg kg⁻¹ (Yim and Nau, 1987) to 180 ± 93 mg kg⁻¹ (Li *et al.*,
291 2001).

292

293 Atmospheric deposition from nearby regions also represents another important input of
294 heavy metals such as Cr, Cu, Pb and Zn to surface soils. According to a quality
295 monitoring program in China (General Administration of Quality Supervision
296 Inspection and Quarantine of the People's Republic of China, 2004), only about 70%
297 of the unleaded petrol samples in China was found to comply with the national standard.
298 In some cases, Pb level was exceeded more than 200 times to the standards. Study on
299 atmospheric deposition in the PRD revealed that the deposition of Cr, Cu, Pb and Zn

300 (6.43 ± 3.19, 18.6 ± 7.88, 12.7 ± 6.72 and 104 ± 36.4 mg m⁻¹ yr⁻¹) was significantly
301 higher when compared with Europe and North America (Wong *et al.*, 2003). Long-
302 range transport of air-borne pollutants or wind-blown contaminated soil particles from
303 Mainland China by the northeast monsoon was reported (Lee and Hills, 2003).
304 Moreover, atmospheric input was reported to be the major contributor of Pb, Cd, As
305 and Hg in agricultural soils in England and Wales (Nicholson *et al.*, 2006), and thus
306 atmospheric deposition, either locally or regionally, may play a significant role for the
307 presence of particle-bound pollutants in soils.

308

309 *3. Comparison of soils cleanup criteria*

310 The soil quality guideline values on the various pollutants investigated imposed by
311 Netherlands (Dutch Guidelines) (Ministry of Housing Spatial Planning and
312 Environment, 2000), Sweden (Soil Remediation Goals) (Swedish Environmental
313 Protection Agency, 2002), England (Kelly Indices) (Contaminated Land Assessment &
314 Remediation Research Centre, 2004) and China (Environmental Quality Standard)
315 (State Environmental Protection Administration of China, 1995) are summarized in
316 Table 3. As Dutch guideline is the most comprehensive and commonly used,
317 comparisons the present findings are made chiefly with the Dutch values. Mercury, Cd
318 and Pb in 138 samples were below the Dutch intervention values, suggesting that the
319 concentrations of these metals in soils were not hazardous to human. In terms of As,
320 Cu, Cr and Zn, most of their levels did not exceed the Dutch intervention values, but
321 there were sporadic soil samples containing levels of As, Cu, Cr and Zn exceeded the
322 intervention values (14, 3, 2, and 8 out of 138 samples correspondingly). Nine out of
323 10 suburban samples from the northern and northeastern New Territories contained As
324 concentrations greater than the Dutch intervention value. Thus, it is suspected that a

325 large part of northern and northeastern in Hong Kong is contaminated with As at
326 concentration that can impose adverse effects on human health. Soil samples with Zn
327 concentration greater than the intervention value were mainly noted in industrial areas,
328 and this is also true for Cu and Cr. For the scarcity and remoteness of the hotspots (Cr,
329 Cu, and Zn), their potential adverse impacts to the general public were kept to
330 minimum. In England, soil remediation is often required before further development
331 on brownfield soils as they are typically contaminated with high levels of heavy metals
332 due to past industrial activities (French *et al.*, 2006). Although leaching of toxic metals
333 to underground water is not a major concern as Hong Kong relies mainly on river water
334 transported from the mainland as well as rainwater collected locally, the fact that more
335 than 10% of the soil samples were highly contaminated with As warrants further
336 investigation. This is especially true if any of these sites (north and north-east of the
337 New Territories) are used for residential development in the future.

338

339 **4. Conclusions**

340 In terms of total concentrations of all the metals (metalloids), industrial and highway
341 areas were the most contaminated. This finding is also true for individual elements
342 (As, Cd, Cr, Cu, Pb and Zn) other than Hg. It was found that Hg concentration was the
343 highest in soil collected from agricultural farmland, which could be attributed to the
344 application of Hg-containing agrochemicals. The use of low quality fertilizers is also
345 believed to be the main source of As, Cu and Zn, while substantial contributions of
346 pollutants by exhausts and wearable parts from automobiles are also suspected.
347 Atmospheric deposition from local and nearby regions is also believed to be a major
348 source of edaphic metals in Hong Kong. A reduction of Pb in soils during the past 10
349 to 15 year was chiefly due to the use of Pb-free petrol. It is expected all the metals

350 (metalloids) would not cause any potential health impacts to the general public, except
351 As, due to its high concentrations in northern and northeastern suburbs in Hong Kong.

352

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367 **Figure Captions:**

368 Figure 1. Kriged maps of pollutants (As, Cd, Cr, Cu, Hg, Pb, and Zn) concentrations
369 (mg kg ⁻¹) in surface soils of Hong Kong.

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371 Figure 2. Plots with PC 1 and PC 2 from principal component analysis as X and Y
372 axis on various pollutants and sampling points. PC 1 was able to explain 49% while
373 PC 2 accounted for another 19% of the total variance. Note that Cd were excluded
374 from PCA because of a large set of not-detected value. A: Biplot showing the loading
375 of 6 pollutants on PC 1 and PC 2. B: Scatter plot of sampling points projecting on the
376 PC 1 and PC 2 plane.

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Table 1. Mean, median, and range of concentration of studied pollutants (mg kg⁻¹) in Hong Kong soils. Note that concentration unit of Hg µg kg⁻¹.

Classified soil categories	Sample no.	Hg			As			Cu			Cd		
		Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range
		Concentration in soils (µg/kg)						Concentration in soils (mg/kg)					
Urban park	39	232	75.0	[N.D. - 3785]	19.4	16.5	[N.D. - 122]	81.41	13.0	[N.D. - 2129]	0.56	0.01	[N.D. - 2.93]
Greening area	14	104	66.0	[N.D. - 311]	26.6	26.6	[N.D. - 97]	21.46	15.1	[N.D. - 59]	0.50	0.01	[N.D. - 2.25]
Country park	9	52	25.0	[N.D. - 128]	36.1	20.3	[3.6 - 95]	11.0	0.01	[N.D. - 93]	0.36	0.01	[N.D. - 2.42]
Rural area	19	75	81.0	[N.D. - 202]	27.6	20.5	[3.2 - 143]	7.32	6.08	[N.D. - 28]	0.37	0.01	[N.D. - 2.91]
Restored landfill	11	50	25.0	[N.D. - 119]	22.0	22.8	[N.D. - 47]	19.3	11.0	[N.D. - 62]	0.85	0.01	[N.D. - 2.86]
Agricultural farmland	9	402	109	[N.D. - 2196]	27.2	15.2	[N.D. - 109]	12.0	6.61	[N.D. - 66]	0.14	0.01	[N.D. - 0.77]
Orchard farm	5	154	72.0	[N.D. - 555]	34.3	30.4	[7.3 - 93]	8.86	5.60	[N.D. - 27]	0.56	0.01	[N.D. - 1.6]
Crematorium	10	75	78.0	[N.D. - 146]	13.8	11.5	[N.D. - 50]	4.29	0.61	[N.D. - 16]	0.13	0.01	[N.D. - 1.21]
Industrial area	18	74	73.0	[N.D. - 237]	25.5	25.4	[N.D. - 61]	52.34	33.3	[N.D. - 396]	1.19	0.67	[N.D. - 4.11]
Nearby highway	4	134	117	[N.D. - 277]	174.6	141	[80.5 - 336]	18.75	15.4	[3.62 - 41]	0.01	0.01	[N.D. - N.D.]
Classified soil categories	Sample no.	Cr			Pb			Zn			Total pollutants		
		Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range
		Concentration in soils (mg/kg)											
Urban park	39	50.5	21.9	[1.85 - 601]	141	130	[11 - 305]	293	197	[13 - 3508]	586	401	[29 - 6553]
Greening area	14	20.8	18.2	[1.23 - 44]	142	144	[104 - 188]	367	300	[114 - 1182]	578	540	[300 - 1351]
Country park	9	7.18	2.00	[N.D. - 23]	75	68	[56 - 115]	75	85	[38 - 110]	204	204	[101 - 357]
Rural area	19	17.0	12.1	[0.81 - 57]	136	124	[53 - 244]	183	135	[43 - 555]	371	377	[155 - 763]
Restored landfill	11	25.1	24.9	[11.8 - 37]	189	180	[47 - 393]	170	146	[79 - 347]	426	425	[221 - 680]
Agricultural farmland	9	22.7	17.9	[7.36 - 54]	121	120	[79 - 161]	197	152	[63 - 564]	380	303	[234 - 845]
Orchard farm	5	16.3	12.4	[5.73 - 34]	104	91	[64 - 186]	116	95	[45 - 243]	280	236	[145 - 479]
Crematorium	10	27.3	21.1	[11.5 - 88]	118	96	[65 - 277]	140	126	[89 - 221]	304	263	[180 - 515]
Industrial area	18	167	29.1	[11.3 - 2486]	221	183	[92 - 493]	529	298	[75 - 1631]	996	617	[214 - 3033]
Nearby highway	4	35.5	35.4	[15.7 - 55]	147	134	[115 - 205]	556	349	[158 - 1367]	932	833	[409 - 1653]

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Table 2. Correlation matrix of investigated metals in different land uses in Hong Kong.

		Urban park							Agricultural farmland						
		Hg	As	Cu	Cd	Cr	Pb	Zn	Hg	As	Cu	Cd	Cr	Pb	Zn
Greening area	Hg	-0.06	0.04	0.2	0.01	0.12	0.03		Hg	-0.2	0.16	-0.23	0.13	0.25	0.08
	As	0.46		-0.04	0.12	-0.07	-0.16	-0.76	As	-0.61		-0.15	0.36	-0.45	-0.55
	Cu	0.13	0.54*		-0.09	0.87*	0.47*	0.98*	Cu	-0.19	0.83		-0.21	0.62	0.53
	Cd	0.14	0.47	0.53*		-0.17	0.15	-0.08	Cd	0.4	0.84	0.73		-0.2	-0.65
	Cr	0.14	0.46	0.80*	0.26		0.49*	0.82*	Cr	-0.14	0.15	0.66	0.15		0.48
	Pb	-0.4	-0.16	0.53	0.19	0.35		0.54*	Pb	-0.1	-0.35	0.23	-0.27	0.87	
	Zn	-0.08	-0.2	0.1	-0.23	0.33	0.13		Zn	-0.17	0.82	0.99*	0.74	0.62	0.2
		Country park							Crematorium						
Rural area	Hg	-0.32	-0.21	-0.51	0.67*	0.52	0.18		Hg	-0.08	0.25	0.18	0.33	-0.16	0.07
	As	0.31		0.3	0.44	0.03	0.09	0.18	As	0.05		0.09	0.85*	0.1	0.14
	Cu	0.41	0.49*		0.01	0.43	0.51	0.1	Cu	0.78*	-0.08		-0.18	0.82*	0.13
	Cd	0.02	0.70*	0.43		-0.23	-0.31	0.47	Cd	0.17	0.08	-0.19		-0.05	-0.16
	Cr	0.37	0.4	0.27	-0.03		0.79*	0.6	Cr	0.07	-0.42	0.02	0.22		-0.05
	Pb	-0.16	-0.22	-0.08	-0.28	-0.1		0.29	Pb	-0.26	-0.14	0.14	-0.11	-0.15	
	Zn	0.48*	-0.03	0.12	-0.2	0.27	0.14		Zn	0.2	-0.31	0.43	-0.21	-0.06	0.4
		Restored landfill													
Nearby highway	Hg	0.07	-0.36	-0.62*	-0.21	-0.23	0.39								
	As	-0.76		-0.43	-0.09	-0.79*	-0.54	-0.4							
	Cu	-0.68	0.77		0.27	0.80*	0.61*	0.51							
	Cd	Nil	Nil	Nil		0.35	0.39	-0.55							
	Cr	-0.84	0.75	0.96*	Nil		0.80*	0.47							
	Pb	-0.67	0.84	0.99*	Nil	0.92		0.19							
	Zn	0.07	-0.42	0.25	Nil	0.27	0.11								

405 Pearson correlation coefficients were shown. Values with * indicated that significant correlations were found at p=0.05.

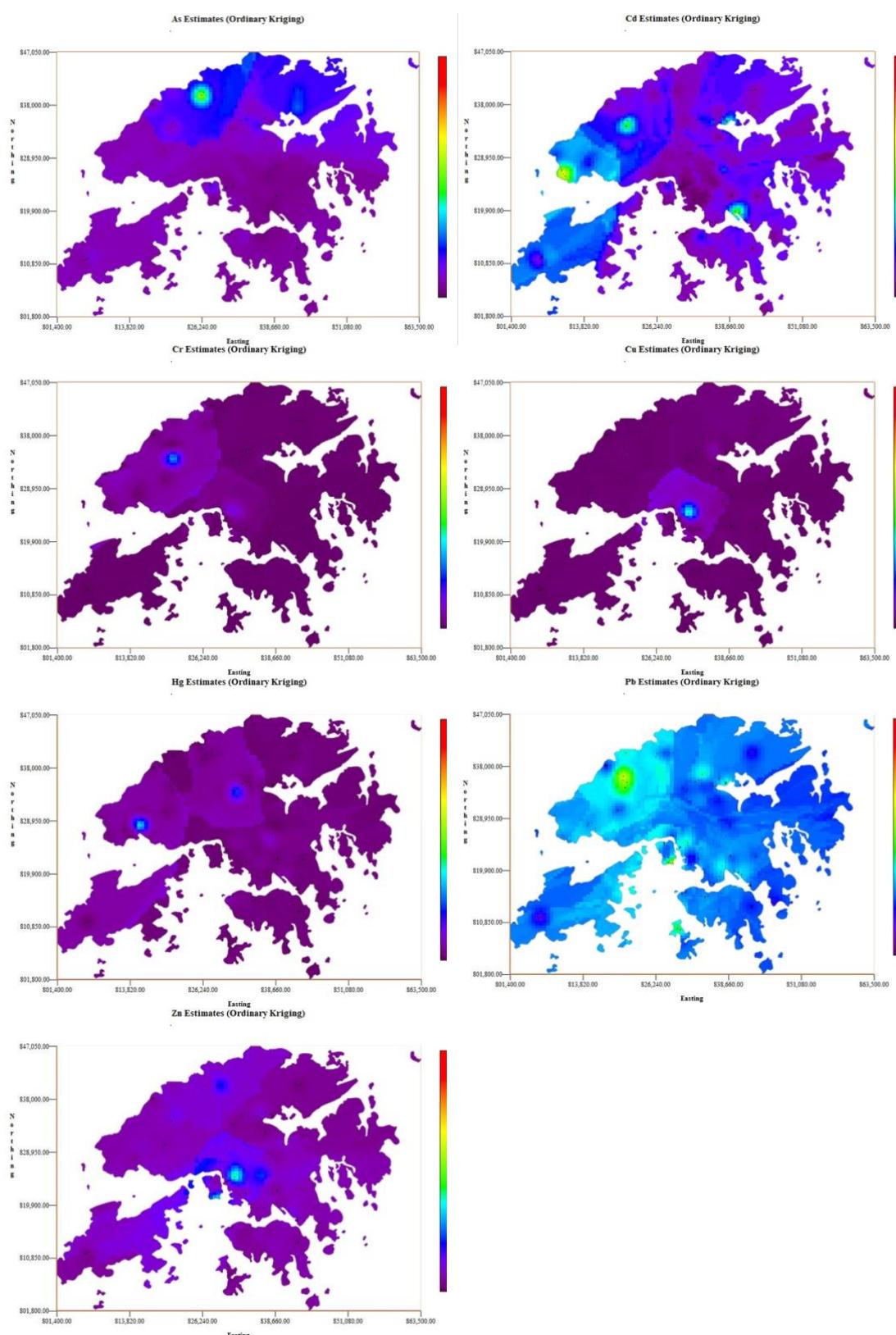
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Table 3. Soil quality guidelines from Netherlands, Sweden, United Kingdom and China, and their recommended values for Hg, As, Cu, Cd, Cr, Pb and Zn in soils.

Country of implementation	Quality guidelines	Hg	As	Cu	Cd	Cr	Pb	Zn
		Concentration in soils (mg/kg)						
Netherlands	Dutch target value	0.3	29	36	0.8	100	85	140
	Dutch intervention value	10	55	190	12	380	530	720
Sweden	Soil remediation goals for sensitive land use	N.A.	15	100	0.4	120	80	350
	Soil remediation goals for less sensitive land use	N.A.	40	200	12	250	300	700
United Kingdom	Kelly	1	30	N.A.	1	100	500	N.A.
China	Environmental quality standard	0.5	30	200	0.6	300	300	250

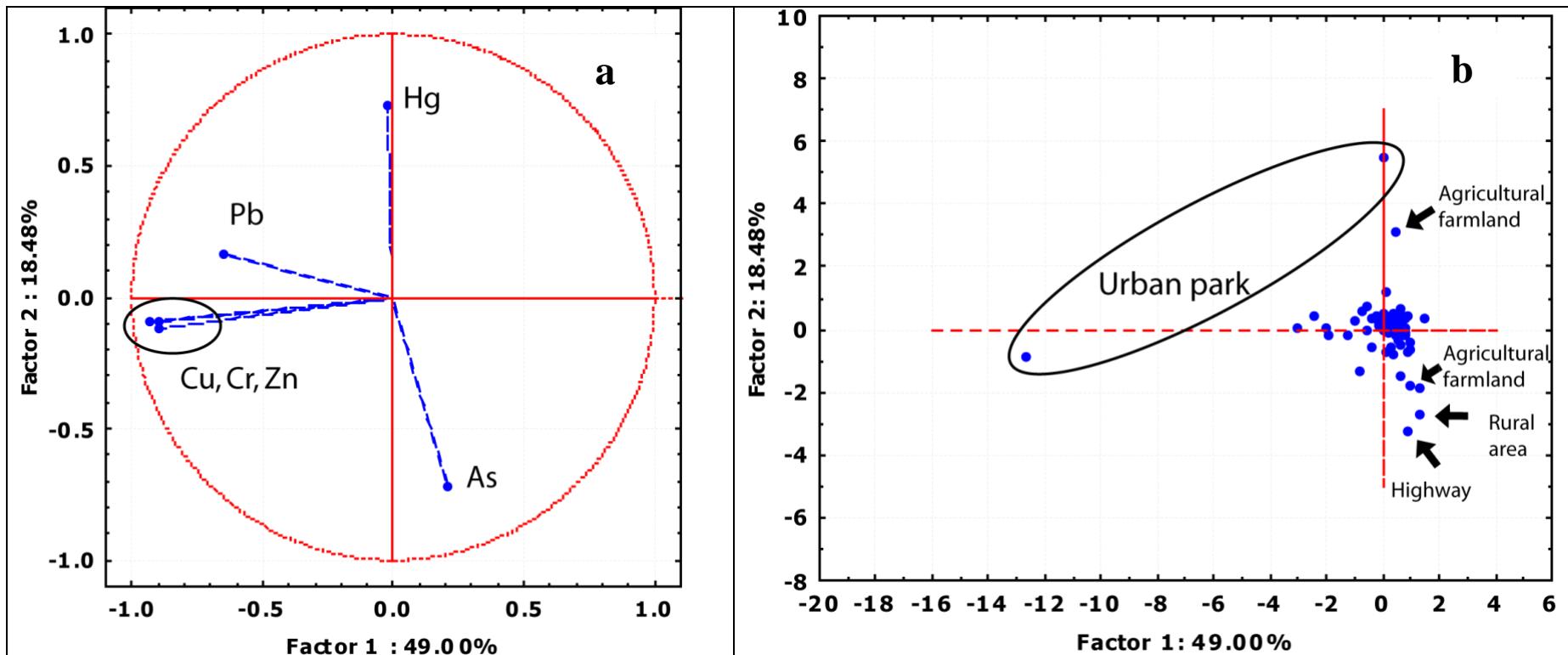
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414 Figure 1. Kriged maps of pollutants (As, Cd, Cr, Cu, Hg, Pb, and Zn) concentrations
415 (mg kg⁻¹) in surface soils of Hong Kong.



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417 Figure 2. Plots with PC 1 and PC 2 from principal component analysis as X and Y axis on various pollutants and sampling points. PC 1 was able to
 418 explain 49% while PC 2 accounted for another 19% of the total variance. Note that Cd were excluded from PCA because of a large set of not-detected
 419 value. A: Biplot showing the loading of 6 pollutants on PC 1 and PC 2. B: Scatter plot of sampling points projecting on the PC 1 and PC 2 plane.

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