The Study of Metal Contamination in Urban Soils of Hong Kong using a GIS-based Approach

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"Capsule": *GIS can be used to identify soil contamination hot-spot areas and to assess potential pollutant sources in an urban community.*

Abstract

The study of regional variations and the anthropogenic contamination by metals of soils is very important for environmental planning and monitoring in urban areas. An extensive survey was conducted in the highly urbanized Kowloon area (46.9 km^2) of Hong Kong, using a systematic sampling strategy with a sampling density of 3 - 5 composite soil samples (0 - 15 cm) per km^2. Geochemical maps of 'total' metals (Cd, Cr, Cu, Ni, Pb and Zn) from strong acid extraction in the surface soils were produced using Geographical Information System (GIS) methods. A significant spatial relationship was found for Ni, Cu, Pb and Zn in the soils using a GIS-based analysis, suggesting that these metal contaminants in the soils of the Kowloon area had common sources. Several hot-spot areas of metal contamination were identified from the composite metal geochemical map, mainly in the old industrial and

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residential areas. A further GIS analysis revealed that road junctions, major roads and industrial buildings were possible sources of heavy metals in the urban soils. The Pb isotope composition of the contaminated soils showed clear anthropogenic origins.

Keywords: Urban soil, heavy metals, GIS, Pb isotope, Hong Kong

1. Introduction

Heavy metal contamination of the environment has been and continues to be a world wide phenomenon that has attracted a great deal of attention from governmental and regulatory bodies anxious to prevent further environmental deterioration and to examine possible methods of remediation. Hong Kong is an urban metropolis with a population of 6.8 million and an area of only 1067 km^2. It is one of the most densely populated areas in the world. Due to Hong Kong's mountainous landscape with limited flat land, many of the residential and commercial structures are concentrated on the hillsides and in the coastal areas surrounding Victoria Harbour. Hong Kong has a well-established network of highways and roads, and many residential estates and commercial buildings are erected beside the roads. They are therefore highly susceptible for pollution from various sources.

Urban soils act as a sink for heavy metals and other pollutants. The possible sources of pollution include vehicle emissions (Harrison et al., 1981; Lau & Wong, 1982; Yassoglou et al., 1987; Surthland et al., 2000), industrial waste (Schuhmacher et al., 1997), the atmospheric deposition of dust and aerosol (Simonson, 1995) and others (Thornton, 1991; Tiller, 1992). As urban areas are densely populated, the environmental quality of urban soil is closely related to human health. Heavy metals in urban areas have been a subject of great concern, due to their non-biodegradable nature and long biological half-lives for elimination from the body (Radha et al., 1997). Most heavy metals in high concentrations have an adverse effect on human health, especially on the health of young children, who have a higher rate of absorption of heavy metals because of their active digestion systems and sensitivity to hemoglobin. Heavy metals may accumulate in our body and affect the central nervous system, causing heavy metal poisoning and acting as cofactors in many other diseases (Hammond, 1982; Nriagu, 1988; Thacker et al., 1992; Schwartz, 1994; Bellinger, 1995).

The heavy metal concentrations of soils have been widely studied in Hong Kong (Wong and Tam, 1978; Lau & Wong, 1982; Yim and Nau, 1987; Wong et al., 1996; Chen et al., 1997; Li et al. 2001; Wong and Li, 2003). According to a survey conducted in 1981 by Lau and Wong (1982) in which the heavy metals in soils of different sectors (recreational, commercial, industrial and minor agricultural) were studied, the highest Cd concentration in Hong Kong was found in a recreational area (Chung Pui), where 54 mg/kg Cd found in roadside soils. The highest Cu concentration (205 mg/kg) was found in an industrial area (Aberdeen). The highest Pb and Zn concentrations in Hong Kong, 229 mg/kg and 259 mg/kg, respectively, were found in an agricultural area (Man Uk Pin). A more extensive survey of all urban parks of Hong Kong was conducted recently (Li et al., 2001), involving the collection of soil samples from more than 60 locations. The average Cd, Cu, Pb and Zn concentrations were found to be highly elevated, at 2.18 mg/kg, 24.8 mg/kg, 93.4 mg/kg and 168 mg/kg, respectively. The highest Cd, Cu, Pb and Zn concentrations in soils were found to be 5.89 mg/kg, 190 mg/kg, 404 mg/kg and 435 mg/kg, respectively. However, attempts to produce an extensive survey using a systematic sampling strategy of urban soils in Hong Kong have been very limited. Moreover, only a few studies have used a GIS-based approach to study heavy metal contamination in an urban environment (Facchonelli et al., 2000) and no GIS-based study in soil quality has ever been conducted in Hong Kong. The Geographical Information System (GIS) is a system for managing, manipulating, analyzing and presenting geographically related information. It is a new approach to refining and confirming geochemical interpretations of statistical output (Mielke et al., 2000; Facchinelli et al., 2000; Gritzner et al., 2001). Geochemical mapping enables the geostatistics information that can be produced by GIS to be visualized and provides a reliable means of monitoring environmental conditions and identifying problem areas.

The present study focuses on the urban area of Kowloon (46.9 km^2), which has the highest concentrations of heavy metals, such as Cd, Cu, Pb and Zn, in Hong Kong (Yim and Nau, 1987, Li et al., 2001). The aims of the current study are: 1) to produce geochemical maps of the heavy metals (Cd, Cr, Cu, Ni, Pb and Zn) and identify possible hot-spots of elevated concentrations of heavy metals using GIS approaches; 2) to assess possible sources of heavy metal contamination in urban soils; 3) to study the natural or anthropogenic origins of heavy metals using Pb isotopic composition analysis. The intention is to use GIS methods to study the interrelationships of heavy metal concentrations in soils with geographical factors, using GIS spatial analysis.

2. Materials and methods

2.1 The study site

Hong Kong consists of three geographical areas, namely Hong Kong Island, the Kowloon Peninsula and the New Territories. Before the 1970s, most residential, commercial and industrial activities were concentrated on Hong Kong Island and the

Kowloon peninsula, while the New Territories were not well developed. In view of the over-crowding in the urban districts, the New Town Development Programme was initiated in 1973, to develop nine new towns in the New Territories, such as Tsuen Wan, Shatin and Tuen Mun. This marks the development of the New Territories, which today contain many large residential, commercial and industrial estates.

Although most of the protected areas in Hong Kong have been highly developed, urbanization is still proceeding, in order to cope with economic advancement and a growing population. Reclamation is presently underway in West Kowloon and Hong Kong Island, to extend the central business district and to construct strategic transportation links (Information Services Department, 2002). The industrial sector in Hong Kong, however, underwent major restructuring in the 1980s and early 1990s. Most of the labour-intensive industries have been moved to China mainland where labour is cheaper. In the last decade, Hong Kong has focused on the development of value-added and technology-intensive industries.

2.2 Soil sampling

In this study, the scope of the sampling area is limited to the Kowloon Peninsula, which has an area of 46.85 km^2. A systematic sampling strategy was adopted to provide a sampling programme for the entire Kowloon Peninsula (Fig. 1). The whole area was divided into 48 cells 1 km x 1 km in size, within which the composite topsoil samples (0-15cm) were collected. Wherever possible, a sampling density of 5 samples per km^2 was used. Each of the composite soil samples was made of 9 sub-samples obtained in a 2 m x 2 m grid using a stainless steel hand auger (Wong et al., 2002). The collected soil samples were stored in polyethylene bags for transport and storage.

The soil samples were air-dried in an oven at 50^{o}C for 3 days. They were then sieved through a 2.0-mm polyethylene sieve to remove stones, coarse materials and other debris. Portions of the soil samples (~20 g) were ground in a mechanical agate grinder until fine particles (<200 μm) were obtained. The prepared soil samples were then stored in polyethylene bags in a dessicator.

2.3. Heavy metal analysis

The ground soil samples (<200 μm) were analysed for major and trace metal concentrations using a strong acid digestion method (Wong and Li, 2003). Approximately 0.250 g of the soil samples were weighed and placed into pre-cleaned Pyrex test tubes. 8.0 ml of concentrated nitric acid and 2.0 ml of concentrated perchloric acid were added. The mixtures were heated in an aluminum block at 50^{o}C for 3 hours, 75^{o}C for 1 hour, 100^{o}C for 1 hour, 125^{o}C for 1 hour, 150^{o}C for 3 hours, 175^{o}C for 2 hours, and 190^{o}C for 3-5 hours until they were completely dry. After the test tubes were cooled, 10.0 ml of 5% HNO_3 was added and heated at 70^{o}C for 1 hour with occasional mixing. Upon cooling, the mixtures were decanted into polyethylene tubes and centrifuged at 3500 rpm for 10 minutes. Metal concentrations of the solutions were measured using Inductively Coupled Plasma - Atomic Emission Spectrometry (ICP-AES; Perkin Elmer 3300DV). The major elements analysed were Ca, Fe, Mg and Mn, while trace metals included Cd, Co, Cu, Cr, Ni, Pb, V and Zn. All glass- and plastic-wares were soaked overnight in a 10% nitric acid solution and rinsed thoroughly with deionized water before use. For quality control, reagent blanks, replicates and standard reference materials (NIST SRM 2709 San Joaquin Soil and an internal reference material), representing 10%, 20%, and 10% of the total sample population, respectively, were incorporated in the analysis to detect contamination and assess precision and bias. The analytical results showed no signs of contamination and revealed that the precision and bias of the analysis were generally < 10%. The recovery rates for the heavy metals and some major elements in the international standard reference material (NIST SRM 2709) were around 75 to 105%.

2.4 Pb isotopic composition analysis

Selected soil samples (15 contaminated soils) were analysed for Pb isotopic composition to detect the input of anthropogenic Pb. Solutions from the strong acid digestion were diluted using a 5% high-purity HNO_3 and analysed for Pb isotopic composition by ICP-MS (Perkin Elmer Elan 6100 DRC^{Plus}). The analytical parameters were set as 190 sweeps/reading, 1 reading/replicate, 10 replicates per sample solution. Dwell times of 40, 25, 25 and 25 ms were used for ^{204}Pb, ^{206}Pb, ^{207}Pb and ^{208}Pb, respectively. The relative standard deviation (RSD) of the 10 replicates was generally below 0.5%. A NIST SRM 981 Common Pb Isotope was used for calibration and quality control. The measured $^{204}Pb/^{207}Pb$, $^{206}Pb/^{207}Pb$ and $^{208}Pb/^{207}Pb$ ratios (0.0647 ± 0.0010, 1.0938 ± 0.0014 and 2.3722 ± 0.0034) of NIST SRM 981 were in close agreement with the standard reference values of 0.0645, 1.0933, 2.3704, respectively.

2.5 Statistical analysis

The analytical results and field condition data were compiled to form a multi-elemental database using Excel and SPSS®. Statistical analyses, such as principle component analysis (PCA) and cluster analysis (CA), were performed using SPSS® statistical software. In the PCA, Varimax with Kaiser normalization was used as the rotation method in the analysis. Since the elemental concentrations varied greatly among the major and trace elements, the raw data were standardized before the execution of clustering in CA. The data were standardized to the Z score (with a mean of 0 and a standard variation of 1) and then classified with the clustering method using the furthest neighbour linkage. The heavy metals that showed a close correlation were identified and grouped for further analysis.

2.6 GIS and spatial analysis

The heavy metal concentrations were used as the input data for a grid-based contouring map, to study the distribution of metals in the urban soils. The software used for the geochemical mapping was SURFER®6.0. A geostatistics method called Kriging was adopted for the interpolation of geographical data. The variogram was used to mathematically express the variance of property changes over the surface, based on the distance and direction separating two sampling locations (Oliver and Webster, 1991). The geochemical maps that were obtained were then overlaid in GIS with other geographical features such as roads, landscapes and buildings. ArcView GIS was used to conduct the spatial analysis for the current study.

GIS was used in this study in the following aspects:

a) To locate the sampling locations in the study area (as Fig. 1.)

b) To generate geochemical maps showing hot-spots of heavy metal contamination in soils (as Fig. 3)
c) To analyse the correlation between the soil metal index and road networks (Fig. 5), locations of industrial buildings (Fig. 6), buildings and landscapes (Fig. 7) using GIS spatial analysis techniques (*e.g.*, overlay)

3. Results and discussion

3.1 Heavy metal concentrations in urban soils

The concentrations of Cd, Co, Cr, Cu, Ni, Pb and Zn in the urban soils of Kowloon are presented in Table 1. In general, the concentrations of heavy metals were in wide ranges, which is typical in urban soils. The mean concentrations of Pb had exceeded the target values recommended by the Netherlands Soil Contamination Guidelines (Department of Soil Protection, 1994) and those of Cd and Zn were close to the target values. For reference, the results of two previous studies on urban soils in Hong Kong (Wong et al., 1996; Li et al., 2001) have also been given in Table 1. The current results are compatible with those of the previous studies.

3.2 Results of Statistical Analyses

3.2.1 Principal component analysis (PCA)

The results of the PCA are presented in Table 2. In the analysis, four principal components were considered, accounting for over 75% of the total variance. Elements such as Cr, Cd and Co were shown to be strongly associated with Fe and Al in the first component (PC1), suggesting a natural input of these metals from parental rocks. The rotated component matrix indicated that Cu, Ni, Pb and Zn were strongly associated in the second component (PC2) with similar high values. These four elements may reflect the anthropogenic contamination in the urban soils. The third component (PC3) included Ca and Mg, which represented a natural geochemical association of major rock-forming elements in soils. Manganese was univocally isolated in the fourth component (PC4) and showed relatively weak association with all of the other elements.

3.2.2 Cluster analysis (CA)

The results of a cluster analysis (CA) of the 152 soil samples are illustrated with the dendrogram in Fig. 2. The elements were hierarchically clustered based on the total metal concentrations in the soils. A criterion for distance cluster of between 15 and 20 was adopted, and 3 distinct clusters were identified (see Fig. 2).

Cluster I: Contained Cu, Ni, Pb and Zn. These elements probably came from a common anthropogenic source.

Cluster II: contained Ca and Mg. The two major elements may be geochemically associated in nature.

Cluster III: contained trace elements such as Cd, Co, Cr and major elements such as Al, Fe and Mn. The heavy metals were geochemically associated with the major elements, which may originate from the soil parental materials.

The results of cluster analysis (CA) agree very well with those of principal component analysis (PCA), depicting a strong association among Cu, Ni, Pb and Zn. It has been shown that the concentration of Pb in Hong Kong is related to Hong Kong's high traffic volumes (Lau and Wong, 1982; Wong et al., 1996). Although Pb has been banned in petrol for a number of years, the concentration of Pb in urban soils still reflects the significant degree of historical Pb contamination and the long half-life of Pb in soils. The mean concentration of Pb in urban soils was found to be 93.4 mg/kg (Li et al., 2001); in the present study it was 94.6 mg/kg. Cu, Ni and Zn may result from vehicle-related activities. ZnO is generally used as an additive in the vulcanization process to strengthen crude rubber in tyre manufacturing (Alloway, 1990); the wear and tear of tyres may contribute to the high Zn content in roadside soils. Copper alloy is a material used in mechanical parts due to its desirable qualities such as corrosive resistance and strength (Bottoms, 2000; Sayed et al., 2003). A Cu-Ni alloy has been used since 1971 in vehicular braking systems by some manufacturers, to replace the traditional steel tubes (Miner, 1993). Copper is also used in Cu-brass automotive radiators due to its high corrosive resistance and high thermal conductivity (Shiga et al., 1990; Nimmo, 1998). The deterioration of the mechanical parts in vehicles over time will result in some of the Cu and Ni being emitted to the surrounding environment.

3.3 Spatial analysis using GIS

The spatial distribution of heavy metals in soils was analysed using GIS methods. The metal concentrations were first interpolated with the Kriging method. The geochemical maps that were obtained were then overlaid with other thematic maps such as road systems, buildings and landscapes (Hong Kong Digital Map, 2001) using the GIS software ArcView3.2.

The geochemical maps of Ca, Fe, Cr, Cd, Cu, Ni, Zn and Pb are presented in Fig. 3. In general, several hot-spots of high metal concentrations were identified in the geochemical maps. The whole Kowloon area is highly urbanized, with an extensive network of roads and high-rise buildings. Similar spatial distribution patterns of Cu, Ni, Zn and Pb were found in the geochemical maps. This provided a refinement and reconfirmation of the results in the statistical analysis, in which strong associations were found among these metals. To identify the sources for these elements, the interpolated values of the four elements were summed up to produce an integrated soil metal index for Cu, Ni, Zn and Pb. The integrated metal index is an indicator of the heavy metal contamination in soils. In the analysis, a 100x100 grid was chosen for the interpolation of each element. The values at the nodes for an individual element were then summed to form the composite maps (see Fig. 4). The regions with percentile values of higher than 75 and 90 were highlighted in Fig. 4. Several hot-spots were identified from the composite geochemical map, including Lai Keng, Cheung Sha Wan, Shek Kip Mei, Kowloon City, Ngau Chi Wan, To Kwa Wan, Ho Man Tin. These are mainly old industrial and residential areas in Kowloon. Therefore, the history of an urban site can contribute to heavy metals in soils.

3.3.1 Effect of roads

The soil metal index was overlaid with the road network in Kowloon using GIS methods. The hot-spots were found to be the junctions of roads and/or near major roads that have a large amount of traffic. The locations of the junctions and major roads, and the concentrations of Cu, Ni, Pb and Zn in the hot-spot areas are summarized in Table 3. One example of these areas (Cheung Sha Wan) is illustrated in Fig. 5. The mean concentrations of Cu, Ni, Pb and Zn in the hot-spot areas were 71.0 mg/kg, 23.8 mg/kg, 231.1 mg/kg and 343.0 mg/kg respectively, which were 3.1, 1.9, 2.4, and 2.7 times the relevant mean concentrations of the whole Kowloon area obtained in the present study. Therefore, the soils in the hot-spot areas were generally about 2.5 times more contaminated than the rest of the urban area. The major sources of these metals may be vehicular emissions, and the mechanical parts and tyres of the vehicles as they are subjected to wear and tear. It should be noted that the hot-spot areas were generally found at the north-east or east side of a major road (see Fig. 5). This may due to the diffusion of pollutants by the prevailing wind in Hong Kong, the southwest monsoon (Hong Kong Observatory, 2002).

3.3.2 Effect of industrial activities

The major industries in Hong Kong are light industries, such as articles of apparel and clothing accessories and electrical machinery and appliances, accounted for 47.1 % and 13.2% in domestic export in 2001, respectively (Information Services Department, 2002). Most of the local factories were small-scale and located in many industrial buildings. To investigate the industrial influences on heavy metal distribution, the soil metal index was related with different buildings in Kowloon using GIS. Some of the hot-spot areas, included Cheung Sha Wan, Shek Kip Mei and To Kwa Wan, were located in close vicinity of industrial buildings. For example, one of the hot-spot areas was found in Cheung Sha Wan where many old industrial buildings were concentrated (see Fig. 6). Industrial activities may play a part, in addition to vehicular emission, for significant heavy metal accumulation in urban soils of Kowloon.

3.3.3 The effects of buildings and landscapes on heavy metal dispersion

The terrace of an urban area, such as Hong Kong, is composed of the natural landscape and high-rise buildings. It has been shown that high-rise buildings can obstruct air movements, and prevent the particulates in air from dissipating (Chen and Mao, 1998). Concentrations of air particles at the lower level of a building were found to be greater than the upper level. In the present study, the buildings and landscape were overlaid with the soil metal index using GIS software and the results are illustrated in Fig. 7. It was found that in the hot-spot areas, the contour lines were denser in locations where buildings were erected and the topographic level was high. The dispersion of heavy metals attached to the surface of air particulates may be obstructed by high-rise buildings and local topographic features. An example was illustrated in Fig. 7. In general, the hot-spots were found mainly located at the low elevation areas where the surrounding landscape was high.

3.4 Pb isotopic composition analysis

The major parent materials of the soils in Kowloon are the Mesozoic plutonic rocks (Sewell, 1999). In the present study, the Pb isotopic composition of pyroclastic rock from Tap Mun Island, Hong Kong (Duzgoren-Aydin et al., 2003), was used to represent the background. The ratios of $^{206}Pb/^{207}Pb$ and $^{208}Pb/^{207}Pb$ for the Kowloon soils are presented in Table 4. The mean $^{206}Pb/^{207}Pb$ ratio of Kowloon soils (1.1802) was significantly lower than the natural background value (1.2206). Similarly, the mean $^{208}Pb/^{207}Pb$ ratio of Kowloon soils (2.4712) was also lower than the natural background value (2.5291). The differentiation in the Pb isotopic composition of the Kowloon soils from the natural background indicated an anthropogenic input of Pb from other sources, possibly from vehicular emissions and industrial activities. The Pb isotopic ratios of the Kowloon soils, the background rocks, the dust in Hong Kong, the vehicular exhaust in the Pearl River Delta (Zhu et al., 2001; Duzgoren-Aydin et al., 2003) are plotted in Fig. 8. As illustrated in Fig. 8, the Pb isotopic ratios of the Kowloon soils were found to form a linear correlation with those of natural background and of the known anthropogenic sources. The results showed that the anthropogenic Pb inputs in the Kowloon soils probably come from emissions from vehicles that used gasoline additives from sources with lower $^{206}Pb/^{207}Pb$ ratios, similar to the Australian Pb ore type.

In Fig. 9, three groups of soils could be distinguished for their different Pb isotope compositions. The classification corresponded very well with the degree of heavy metal contamination in the soils (low, medium and high). The highly contaminated soils had Pb isotopic compositions that were more closely corresponding to the vehicle emission sources (e.g. Australian Pb ore) than other soils. The result indicated that the highly contaminated soils had more anthropogenic inputs (traffic emissions *etc.*) than those less contaminated soils.

4. Conclusion

The geochemical maps of Cd, Cr, Cu, Ni, Pb and Zn in the urban soils of Kowloon were produced using GIS methods. Copper, Ni, Pb and Zn showed strong associations with each other, reflecting the heavy contamination in these urban soils. An integrated soil metal index was established by adding up the Cu, Ni, Pb and Zn concentrations from individual element geochemical maps. Several hot-spot areas were identified in the composite geochemical map. Using GIS spatial analysis methods, the majority of the hot-spot areas were identified to be road junctions and/or sites next to major roads, suggesting that vehicular emissions and the wear and tear of mechanical parts in vehicles may be the major sources of heavy metals in urban soils.

Some hot-spot areas are located close to industrial sites, indicating that industrial activities may also contribute to the accumulation of heavy metals in urban soils. The analysis of Pb isotopic composition suggested strong influences of anthropogenic origins of Pb in these urban soils. The study demonstrated that GIS can be used in a study of urban soil contamination to produce geochemical maps, identify hot-spot areas and assess the potential sources of pollutants in an urban community.

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Table 1
Metal concentrations (mg/kg) of urban soils in Hong Kong and the target and intervention values (mg/kg) from the Netherlands Soil Contamination Guidelines

Location		Cd	Co	Cr	Cu	Ni	Pb	Zn
Urban Soil	Range	0.10-5.59	0.24-6.09	8.03-92.0	0.76-117	5.29-40.1	12.1-360	20.7-577
(Kowloon)	Mean	0.62	3.33	23.1	23.3	12.4	94.6	125
(n=152)	Median	0.52	3.02	21.6	16.0	11.2	77.2	92.1
	Std. Dev.	0.82	2.16	10.1	23.4	4.87	61.0	89.1
Urban Soil[a] (n=594)	Mean	2.18	-	-	22.3	-	89.7	146
Urban Soil[b] (n=70)	Mean	1.89	-	-	27.5	-	100	93.9
Guideline[c]	Target Value	0.8	20	100	36	35	85	140
	Intervention Value	12	240	380	190	210	530	720

[a] Li et al. 2001
[b] Wong et al. 1996
[c] Department of Soil Protection, Netherlands, 1994

Table 2
Matrix of principle component analysis loadings of heavy metals and major elements of Kowloon urban soils

	Principal loading factors			
	PC1	PC2	PC3	PC4
Al	***0.705***	-0.065	-0.485	-0.078
Ca	-0.031	0.268	***0.761***	0.051
Cd	***0.574***	0.292	0.155	0.139
Co	***0.778***	0.124	0.159	0.316
Cr	***0.600***	0.527	0.142	0.092
Cu	0.005	***0.908***	0.148	-0.047
Fe	***0.919***	0.150	0.082	0.152
Mg	0.497	0.002	***0.768***	-0.036
Mn	0.209	-0.054	-0.016	***0.919***
Ni	0.367	***0.728***	0.142	-0.041
Pb	0.220	***0.623***	-0.233	0.530
Zn	0.114	***0.910***	0.157	0.049

Table 3
Locations and mean concentrations of heavy metals at road junctions and next to major roads and the mean values in Kowloon soils.

	District	Location	Sample ID	Cu (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	Soil Index[b] (mg/kg)
Road Junction	Cheung Sha Wan	Cheung Sha Wan Rd/ Kwai Chung Rd/ Lai Chi Kok Rd	K12-3	103	21.3	131	477	732
	Ngau Chi Wan	Kwun Tong Rd/ Lung Chueng Rd/ Clear Water Bay Rd	K18-1	113	18.1	330	577	1040
	Ho Man Tin	Pui Ching Rd/ Princess Margeret Rd	K32-1	41.2	17	216	245	519
Next to a Major Road	Lai Keng	Castle Peak Rd	K1-4	15.1	11.9	360	113	500
	Shek Kip Mei	Tai Po Rd	K14-3	50.5	20.9	266	374	711
	Kowloon City	Concorde Rd	K16-2	89.4	37.6	171	302	600
	To Kwa Wan	Kowloon City Rd	K25-1	84.9	40.1	145	313	583
Kowloon Soils[a]				23.3	12.4	94.6	125	255

[a] mean concentrations of heavy metals in the present study (n=152)
[b] the soil index is the summation of metal concentrations (Cu, Ni, Pb and Zn)

Table 4
Lead concentrations and isotopic compositions of 15 selected urban soils in Kowloon

	Sample ID	$^{204}Pb/^{207}Pb$	$^{206}Pb/^{207}Pb$	$^{208}Pb/^{207}Pb$	Pb conc. (mg/kg)	Range of Pb Contamination
Bedrock of Tap Mun Island (HK)[a]		0.0636	1.2206	2.5291	12	-
Kowloon Soils	K9-5	0.0633	1.2246	2.5142	12.1	Low <30 mg/kg
	K11-3	0.0635	1.2019	2.4950	18.4	
	K39-3	0.0634	1.2275	2.5335	19.6	
	K11-1	0.0636	1.2154	2.5163	22.5	
	K23-3	0.0634	1.2170	2.5238	26.4	
	K40-3	0.0637	1.1847	2.4731	80.3	Medium 80-100 mg/kg
	K34-1	0.0636	1.2095	2.5102	82.9	
	K13-3	0.0637	1.1818	2.4732	84.9	
	K33-4	0.0637	1.2004	2.4984	85.9	
	K13-2	0.0638	1.1778	2.4688	92.3	
	K32-3	0.0644	1.1314	2.4087	203	High >200 mg/kg
	K11-5	0.0641	1.1350	2.4141	211	
	K32-1	0.0641	1.1352	2.4190	216	
	K14-3	0.0646	1.1324	2.4149	266	
	K18-1	0.0648	1.1283	2.4050	330	

[a] Duzgoren-Aydin et al. 2003

Figure Captions

Fig. 1. Sampling locations in Kowloon of Hong Kong (n=152).

Fig. 2. Dendogram of the cluster analysis based on the correlation coefficients using the furthest neighbour linkage method.

Fig. 3. The geochemical map of Ca, Fe (major elements) and Cd, Cr, Cu, Ni, Pb, Zn concentrations in urban soils of Kowloon.

Fig. 4. Geochemical map showing hot-spot areas of heavy metal contamination in the urban soils of Kowloon.

Fig. 5. Soil metal index (Cu, Ni, Pb and Zn) plotted on a regional map and overlaid with road networks (K1-1, K1-2 etc. in the map are referred to the specific sampling locations).

Fig. 6. Soil metal index (Cu, Ni, Pb and Zn) plotted on a regional map and overlaid with buildings showing the locations of industrial sites (K1-1, K1-2 etc. in the map are referred to the specific sampling locations).

Fig. 7. Soil metal index (Cu, Ni, Pb and Zn) plotted on a regional map and overlaid with buildings and landscapes (K1-1, K1-2 etc. in the map are referred to the specific sampling locations).

Fig. 8. $^{206}Pb/^{207}Pb$ and $^{208}Pb/^{207}Pb$ ratios of urban soils in Kowloon and other environmental samples in the surrounding Pearl River Delta.

Fig. 9. $^{206}Pb/^{207}Pb$ and $^{208}Pb/^{207}Pb$ ratios of contaminated urban soils in Kowloon.