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A comparative study of heavy metal concentration and distribution in deposited street dusts in a large and a small urban area: Birmingham and Coventry, West Midlands, UK

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Abstract

Results are presented from a study of the distribution of heavy metals in street dusts of two cities in Midland England. The first (Birmingham) is a large urban area (population of 2.3 million), the second, Coventry, a small one (population of 0.3 million). Several trends were identified from Birmingham: higher concentrations were located near industrial areas in the northwest of the city and within the ring road. However, lower concentrations were found to the southwest in areas of mainly residential properties and parks. High values were also identified in association with junctions controlled by traffic lights where vehicles were likely to stop regularly. This last trend was further investigated in Coventry, where it was found that concentrations of heavy metals at junctions controlled by traffic signals and by pedestrian-controlled pelican lights (Mounted Pelican Controller, MPCs) were lower than those found in Birmingham, apart from Ni.

Keywords: Comparative study; Heavy metal concentration; Street dusts

1. Introduction

Interest in the levels of contaminants associated with street dusts has risen in the last decades, particularly in light of the impact of high blood–Pb levels in children living in urban areas and the likelihood of this being caused by inadvertent hand–mouth contamination caused while the child plays in a city street (Akhter and Madany, 1993). Many studies throughout the world have identified the sources of these contaminants in street dust as those associated with vehicular traffic, industrial and residential areas as well as weathering of building facades, and have in fact recognised street dust as a significant pollution source itself (Akhter and Madany, 1993). Table 1 summarises the concentrations of heavy metals published in some of these studies showing the range of values found globally.

Various trends can be identified on examination of results from street dust studies throughout the world:

1. Spatially, the total concentrations of heavy metals have been related to industrial and residential areas (Davies et al., 1987; Kim et al., 1998; Dong et al., 1984) as well as traffic movements, numbers of vehicles and their speed (Day et al., 1975; Leharne et al., 1992; Ellis and Revitt, 1982; Hamilton et al., 1984).
2. Comparison of the populations of the cities in Table 1 with heavy metal concentrations is summarised in Table 2. In general, the larger the population, the higher the heavy metal concentration in street dust; this is particularly true of Cd and Pb. The correlation coefficient for Ni is low, but may be a reflection of the few studies (6) which examined this element.
3. Sequential extractions have identified Cd as the most bioavailable element as it has the highest percentages bound to operationally defined exchangeable sites and carbonates. Zn and Pb are mainly associated with carbonates and then Fe/Mn oxides, but not the exchangeable fraction. The vast proportion of Cu is bound to

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Table 1
Global studies of individual heavy metal concentrations, ranges of concentrations, comparisons between urban and industrial sites and years in street dusts (μg g^{-1} unless otherwise stated) in population order

City	Ref	Metal				
		Cd	Cu	Ni	Pb	Zn
New York (population = 16 972 000)	1	8	355	Nd	2582.5	1811
Seoul (population = 10 627 000)	2	3	101	Nd	245	296
London (population = 9 227 687)	3	6250	61–323	32–74	413–2241	Nd
London	4	Nd	111–512	Nd	544–1636	988–3358
London	1	6.5	197	Nd	3030	1174
London	5	2.7	108	Nd	2100	539
Hong Kong (population = 5 448 000)	4	Nd	92–392	Nd	208–755	574–2397
Madrid (population = 2 909 792)	6	Nd	188	44	192.7	476
Gtr M'chstr (population = 2 578 900)	7	Nd	Nd	Nd	970	Nd
B'ham (population = 2 329 600)	8	residential/ industrial	1976		1300/950	
B'ham	8	residential/ industrial	1987		791/527	
Taejon, Korea (population = 2 000 000)	9	Nd	47–57	Nd	60–52	172–214
Amman (population = 1 272 000)	10	2.5–3.4	69–117	27–32.8	219–373	Nd
Cincinnati, from 1990 to 1998 (population = 1 539 000)	11	Nd	1219/253	Nd	662/650	Nd
Oslo (population = 758 949)	6	1.4	123	41	180	412
Bahrain (population = 549 000)	12	72	Nd	126	697	152
Hamilton (population = 322 352)	13	4.1	129	Nd	214	645
Christch'ch (population = 308 200)	1	1	137.3	Nd	1090.5	548
Urbana (population = 36 344)	14	1.6	Nd	250	0.1%	320
Lancaster (population = 136 700)	5	3.66	75	Nd	1090	260

Populations given under the first appearance of city name. Number given next to city name refers to reference (Ref) given below table. Nd = no data available.
References: (1) Fergusson and Ryan, 1984; (2) Chon et al., 1995; (3) Leharne et al., 1992; (4) Wang et al., 1998; (5) Harrison et al., 1981; (6) De Miguel et al., 1997; (7) Day et al., 1975; (8) Davies et al., 1987; (9) Kim et al., 1998; (10) Jiries et al., 2001; (11) Tong, 1998; (12) Akhter and Madany, 1993; (13) Droppo et al., 1998; (14) Hopke et al., 1980.

organic matter and is least likely therefore to be made available to the environment under normal conditions. In general, the index of bioavailability in six studies throughout the world was Cd>Zn = Pb>Cu (Droppo et al., 1998; Wang et al., 1998; Fergusson and Ryan, 1984; Harrison et al., 1981; Serrano-Belles and Leharne, 1997; Li et al., 2001).

4. Fergusson et al. (1980) and Ellis and Revitt (1982) noted a trend for higher concentrations to be found on streets where traffic was more likely to undergo stop–start maneuvers such as at traffic lights.
5. According to Akhter and Madany (1993), the regular occurrence of long, dry spells should affect the residence time of street dusts, and hence heavy metal concentrations, but no other studies were found which reported this. While weather is likely to influence heavy metal distribution, concentration and retention time, other factors previously discussed here probably have a greater impact, particularly in temperate regions.
6. Previous studies of street dust contaminant concentrations in Birmingham were published in 1976 and 1982 (compared in Davies et al., 1987) and in soils by Thornton (1990), some results from which are included in Table 1. However, these studies were rather limited in extent, concentrating only on a comparison of Pb concentrations in residential and industrial areas. However, they found higher values associated with industrial locations, and that concentrations in both areas had declined after 11 years. There have been no similar studies specifically examining street dusts in Coventry.

Table 2
Correlation of city population with heavy metal concentration using data from Table 1 (where *r* = significance level, *n* = number of samples)

	Pb	Zn	Ni	Cu	Cd
	0.624**	0.536*	− 0.303	0.593*	0.779*
n	23	17	6	17	13
r	0.4	0.46	0.75	0.46	0.55

* Significance to 0.05%.
** Significance to 0.01%.

Street dusts are characterised by short residence times: "although they may contain substantial metal concentrations, street dusts represent only rather recent accumulation of pollutants" (Harrison et al., 1981, p. 1379). Allott et al. (1990) computed residence times of up to 250 days for street dusts in Barrow-in-Furness, UK, qualified by the statement that residence times "...will be site specific due to variations in the local processes." (p. 410). However, material making up street dust includes eroded urban soils which may have historical metal pollution associated with it. De Miguel et al.

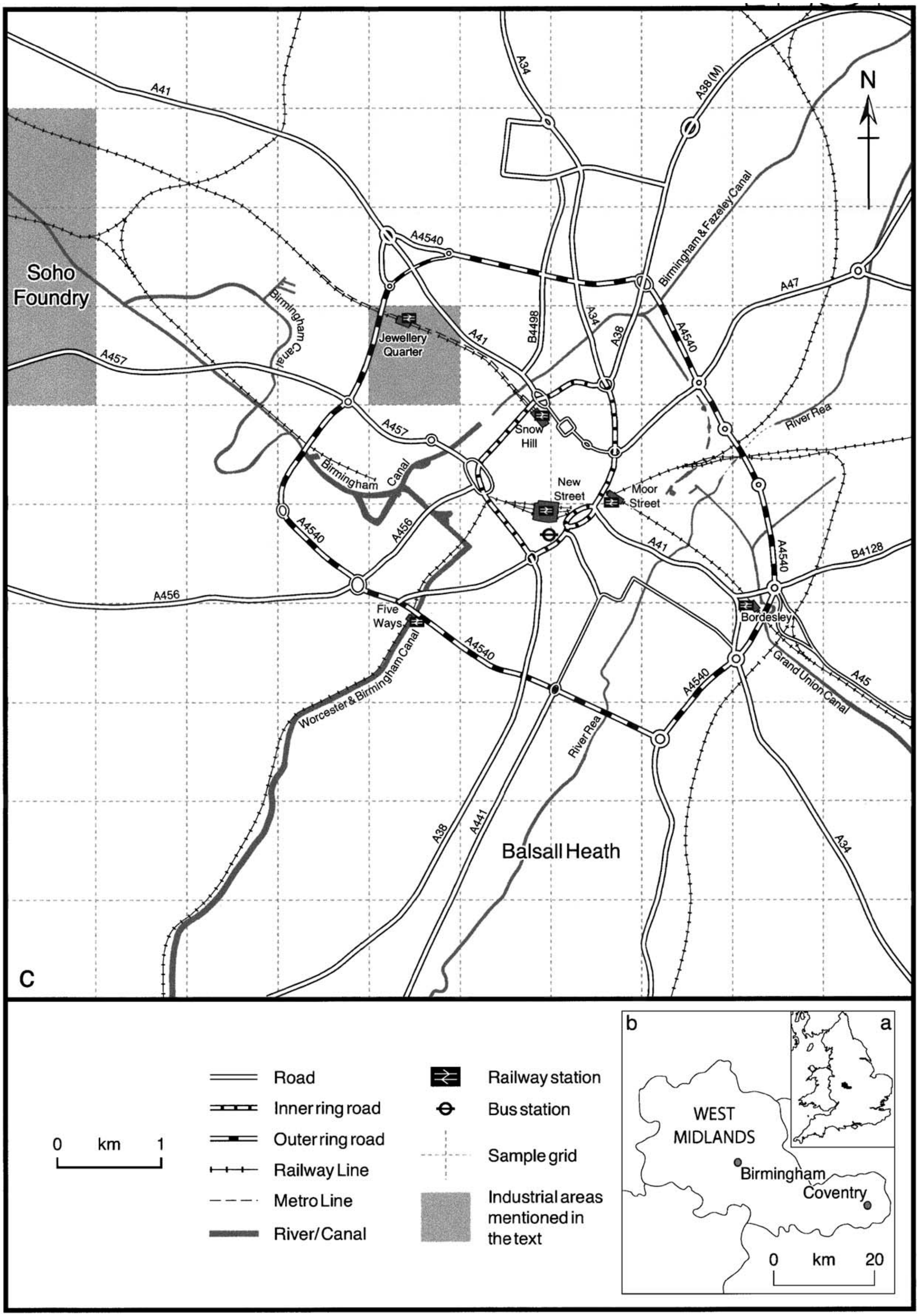

Fig. 1. (a) The location of the West Midlands in the UK. (b) The location of Coventry and Birmingham in the West Midlands. (c) The location of the sampling stations in Birmingham and of industry, the public transport network, main roads and Balsall Heath.

(1997) found high Pb concentrations in Madrid associated with a smelter which had closed down several years before the study took place. Since both Coventry and Birmingham have had heavy industry in the past, soils may retain any historical contamination, and street dust will therefore reflect this, as well as current traffic movements, industrial and urban processes. Soil represents only one of many sources making up the dust that settles on city streets. Other sources include organic matter from discarded foodstuffs, animal faeces or that growing in drains, etc., corroded metal work, weathered building facades, emissions from vehicle exhausts or industrial chimneys. Street dust is therefore a complex ‘‘cocktail’’ of material (Robinson et al., 2000).

The aims of this study were threefold; firstly to examine the spatial distribution of heavy metals found in street dusts in Birmingham and to identify controlling factors in their distribution. The second aim was to apply these factors to Coventry street dusts to ascertain their relative importance in a different city. The third aim was to assess the hazard to human health these dusts may represent.

2. Methodology

This study examines the concentrations of heavy metals in street dusts in two cities at two spatial scales: a city-wide grid across the City of Birmingham and a smaller scale study in the City of Coventry, both in West Midlands, UK. The Coventry study focused on dusts accumulating on streets near pedestrian-operated Pelican crossings, or a Mounted Pelican Controller (MPC) which force traffic to undertake stop–start maneuvers. A further study of a small sample of street dusts used a sequential extraction of heavy metals based on Tessier et al. (1979), which Droppo et al. (1998) suggest can be used as an indication of bioavailability. Direct assessment of bioavailability can only be made using toxicity testing.

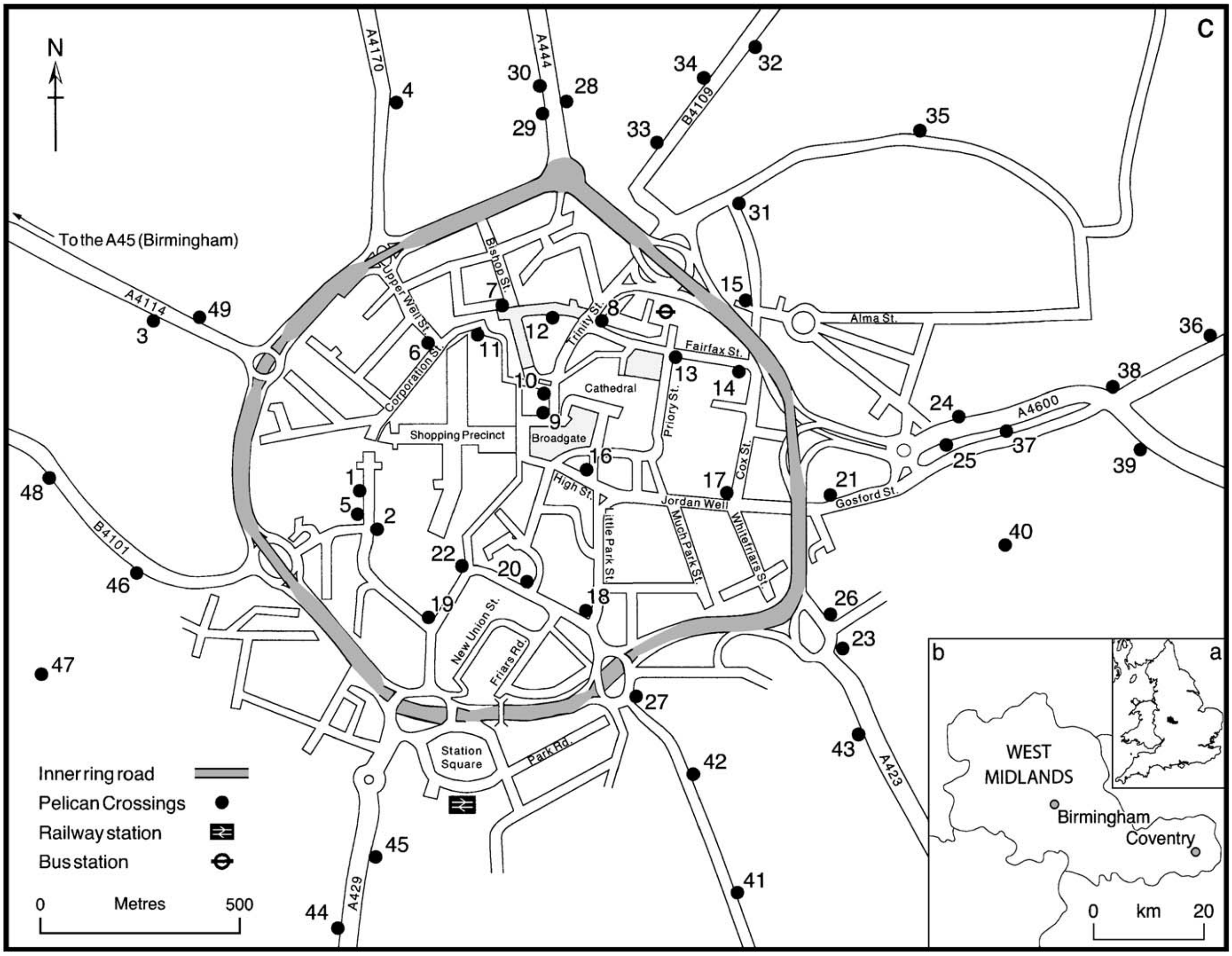

Fig. 2. (a) The location of the West Midlands in the UK. (b) The location of Coventry and Birmingham in the West Midlands. (c) The location of the sampling stations in Coventry and of industry, the public transport network and main roads.

3. Field sites and sampling methods

Both Birmingham and Coventry are located in the West Midlands of UK (Fig. 1a and b). Birmingham is the second largest city in England after London. It has a population of more than 2.3 million, nearly seven times that of Coventry's 301 300.

Birmingham was chosen because it has industrial, residential and pedestrianised areas as well as green spaces (Fig. 1c). Being much smaller, the majority of industry in Coventry (Fig. 2c) is located outside its single ring road. Birmingham has an inner and an outer ring road with the city centre located in the northern third of the inner ring road. Major industry in both Birmingham and Coventry is located outside the ring roads, although lighter industrial areas such as the Jewellery Quarter in Birmingham are located between the inner and outer ring roads. Main bus and train stations in both cities are located either within the ring roads or very close by (Figs. 1c and 2c).

4. Sampling strategy and analytical protocol

The Birmingham sampling grid is shown in Fig. 1c. Samples were taken as close as possible to the centre of the 0.7-km^2 grid square, where this was impossible, i.e. Edgbaston Reservoir is located in the centre of a grid square located in the southwest Birmingham, the sample was taken as close as possible to the centre. In the case of Coventry, the City Council was approached for a location map of pelican crossings in the city and 49 locations within and around the ring road were selected.

For both studies, sampling was undertaken over three consecutive days, in the summer after a dry spell of weather.

The samples were collected using a clean plastic dustpan and brush as outlined by Charlesworth and Lees (1999a,b) and Akhter and Madany (1993) from a 1-m^2 area using a quadrat. In a study of the distribution of heavy metals deposited in association with dusts on a motorway, Johnston and Harrison (1984) found that the highest concentrations were located in the centre of the road, with concentrations decreasing towards the gutter at either side of the road. Harrison et al. (1985) quantified this reduction in concentration to the gutter dusts containing 10% of the total heavy metal output from motor vehicles still a substantial proportion of the total. Dusts were collected from gutters in Birmingham for safety reasons, but this may mean that concentrations are likely to be lower than if the centre of the road were sampled. In Coventry, since the crossing was controlled by pedestrians, the pavement and pavement edge were sampled close to the MPC where the pedestrian would have to wait prior to the traffic lights changing.

In previous studies of urban dusts and sediments in Coventry, Charlesworth and Lees (1999a) collected a suite of over 50 samples which included some street dusts. An extension to this study included a sequential extraction of some of this material (Charlesworth and Lees, 1999b), a limited number of which were street dusts collected from the area covered by the present study. These have been separated from the database and are reported here.

Fig. 3 is a flowchart of the analytical protocol followed for all the case studies where a total digestion was used. The protocol used for the sequential digestion technique was adapted from that of Tessier et al. (1979), which identified the following five operationally defined associations:

1. Exchangeable or adsorbed trace metals. These are loosely bound to the substrate and would change in concentration with changes in ionic composition of the overlying water. This fraction was extracted for 1 h at room temperature using 1-M sodium acetate at pH 8.2 with continual agitation.
2. Metals bound to detrital carbonates. Changes in environmental pH would affect the binding of metals to carbonates. Extracted at room temperature for 5 h with 1-M sodium acetate at pH 5 with continual agitation.
3. Metals coprecipitated with Fe and Mn oxides as coatings on particles, or as cements binding sediment particles together. These are extracted using 0.3-M sodium dithionite, 0.175-M sodium citrate and 0.025-M hydrogen citrate.
4. Metals associated with organic matter or sulphides can either be incorporated into the tissues of living organisms, deposited as detritus or can be found as a coating covering grains. Metals associated with organic matter would be released into the environment under oxidising conditions. The organic fraction was extracted using 0.02-M nitric acid and 30% hydrogen peroxide.
5. The residual fractions of the heavy metals are those trapped in the crystal lattices of primary and secondary minerals. Residual elements are only released to the environment upon complete destruction of the crystal in

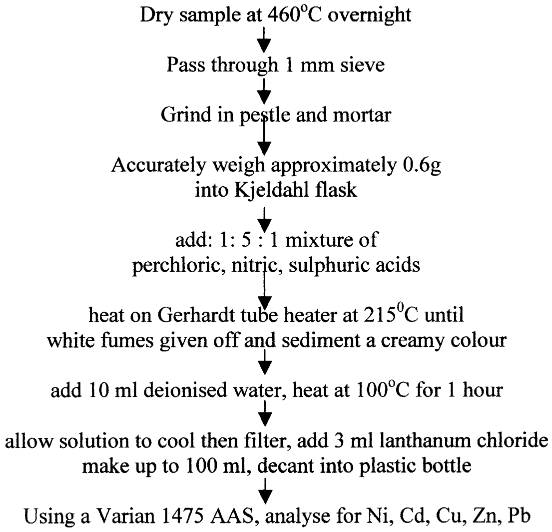

Fig. 3. Analytical protocol.

which they are found and were extracted using a mixture of concentrated sulphuric, nitric and perchloric acids in the ratio 1:5:1 v/v.

Concentrations of the heavy metals in each extract were determined using a Varian 1475 atomic absorption spectrophotometer.

5. Results and discussion

5.1. General trends across the Coventry and Birmingham studies

Descriptive statistics for both locations are presented in Table 3 which shows the wide range of values found for each metal. Skewness indicates that only Pb in Birmingham and both Pb and Ni in Coventry approach normal distributions, the other heavy metals being positively skewed towards the lower concentrations with one or two very high values accounting for the long tail found in many of the distributions. Comparison of data in Tables 1 and 3 shows that each study generated heavy metal concentrations that were comparable with other similar studies.

Table 3
Descriptive statistics for heavy metals found in street dusts

	Zn	Ni	Pb	Cd	Cu
(a) Birmingham in general (n = 100) and Balsall Heath in particular (n = 2)					
Mean	534.0	41.1	48.0	1.62	466.9
SE on mean	47.0	9.2	2.9	0.23	98.7
Median	388.4	16.6	48.6	0.0	165.6
Skewness	3.1	5.5	0.58	1.9	4.5
Minimum	81.3	0.0	0.0	0.0	16.4
Maximum	3164.8	636.2	146.3	13.1	6688.4
Balsall Heath	1089.4	0.0	146.3	6.5	178.9
(b) At Coventry Pelican crossings (n = 49) (mg kg^{-1}) (SE = Standard Error)					
Mean	385.7	129.7	47.1	0.9	226.4
SE on mean	61.0	8.7	8.4	0.27	25.7
Median	300.0	141.5	21.4	0.0	151.6
Skewness	5.3	−0.073	1.16	2.5	1.8
Minimum	93.0	6.18	0.0	0.0	49.3
Maximum	3038.2	233.5	199.4	8.9	815.0

(c) Published "Trigger Concentrations"

Contaminants	Planned uses	Trigger concentrations (mg kg^{-1} air-dried soil)
Group A: Contaminants which may pose hazards to health		
Cd	Domestic gardens, allotments, parks, playing fields	3
	Open space	15
Pb	Domestic gardens, allotments, parks, playing fields	500
	Open space	2000
Group B: Phytotoxic contaminants not normally hazardous to health (all in their "available" form)		
Cu	Any uses where plants are to be grown	50
Ni	Any uses where plants are to be grown	20
Zn	Any uses where plants are to be grown	130

Source: ICRCL (1983).

Table 4
Correlation coefficients between the heavy metals in the two studies: (a) Birmingham and (b) Coventry Pelican crossings

(a) $n = 100$, $r = 0.194$	Zn	Ni	Pb	Cu
Zn		0.278**		0.782**
Ni	0.278**			0.367**
Cd			0.236*	
Cu	0.782**	0.367**		

(b) $n = 49$, $r = 0.262$	Ni	Cd
Pb	− 0.519**	0.281*

Where: n = number of samples, r = significance level.
Where there was no correlation between elements, the individual metals are not included in the table.
* Significance to 0.05%.
** Significance to 0.01%.

Table 2 suggested that there was a relationship between the population of a city and the concentrations of heavy metals found in the deposited street dust. It might therefore be expected that the dust collected from Birmingham would have higher concentrations of heavy metals than that collected from Coventry. This is, in fact, the case for all metals except Ni, where the mean concentration in Coventry street dust (Table 3) is nearly three times that found in Birmingham street dust. Pb levels are only slightly higher in Birmingham in comparison with those in Coventry.

Table 4 shows correlation coefficients between each of the metals in the two studies and indicates that Cd and Pb are significantly correlated at both locations. The MPC study only appears to indicate a relationship between Pb and Ni, Pb and Cd, with only Pb and Ni significant at the 0.01 level. The Zn/Cu correlation in the Birmingham study is further illustrated by the distribution of both elements (Fig. 4c and d) which show high concentrations across the central W–E transect common to both elements.

5.2. The spatial distribution of heavy metals in (a) Birmingham and (b) Coventry street dusts

5.2.1. Birmingham

Fig. 4a–e shows the distribution of the metals across the grid of 100 samples in Birmingham.

As has already been discussed, the trends for Zn and Cu are similar with higher concentrations trending W–E across the centre of the grid, within the inner and outer ring roads. According to Jiries et al. (2001), Zn and Cu may be derived from the mechanical abrasion of vehicles and the location of high values in Birmingham may therefore be related, in part,

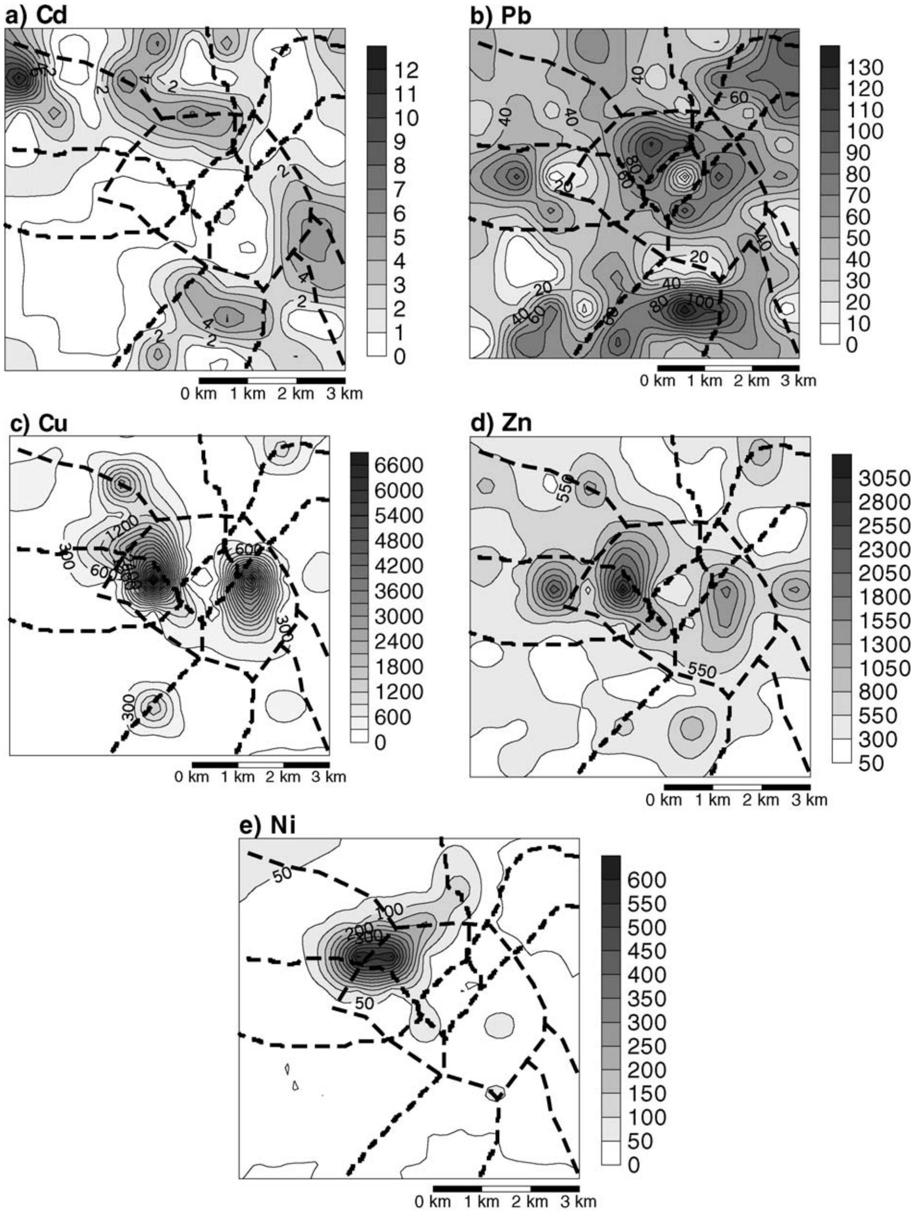

Fig. 4. Spatial distribution of heavy metals (μg g^{-1}) in the street dusts of Birmingham. (a) Cd, (b) Pb, (c) Cu, (d) Zn and (e) Ni.

to traffic movements. The highest values for Ni, Cu and Zn are located between the outer and inner ring roads to the west, and while the correlation coefficients between Ni and Zn, Ni and Cu are not as high as that between Zn and Cu, the significance is still at the 0.01 level (Table 4), and so may be from the same source as Zn and Cu. Since the Jewellery Quarter is located where high concentrations of Zn, Ni and Cu are found, the source of these three elements may be associated with silver working in this area. Both legal alloys used in the production of coinage in Britain use Cu as their alloying element and Hardenable silver uses small amounts of Ni in its production (Street and Alexander, 1994).

Zn and Cd are also associated with tyre wear (Ellis and Revitt, 1982), and Zn in particular is associated with oil spills on road surfaces. However, there is little evidence for any relationship between the distribution of Cd and Zn commensurate with their deposition together on road surfaces due to the wear of tyres. It would therefore seem that there is an alternative source of Cd. Comparing the spatial distributions (Fig. 4a–e) of all five heavy metals, Cd is the only one with a hotspot (>12 μg g^{-1}) in the northwest of the grid, where the Soho Foundry and metal works are located. While now engaged in the production of electronic retail and industrial weighing scales (Cooper, 1994), historically, this site was a brass foundry involved in the production of furniture and coins. While Cu and Zn are used in the production of the brass alloy itself, Cd was used to protect the surface of the brass from corrosion. Fig. 4a shows that 52 of the grid squares were lower than the levels of detection for Cd. There are no grid squares in which the levels of either Zn or Cu are this low and the values for Zn (915.0 mg kg^{-1}) and Cu (424.8 mg kg^{-1}) for the Soho Foundry grid square are higher than 90% and 85% of all the other values in the dataset, respectively. It would therefore seem that the distribution of Zn and Cu across the city can be explained by their association with traffic, but that industry and the Jewellery Quarter have locally enriched the dusts in these areas.

The correlation between Pb and Cd is only significant at the 0.05 level, but their spatial distributions are similar and evenly distributed throughout the grid, both metals having hot spots located in the south of the grid and also associated with the outer ring road. An interesting hot spot, particularly for Pb, was located to the southeast of the grid in Balsall Heath where road humps and traffic calming measures slow traffic down. Comparing the mean values across the whole Birmingham database, Table 3 shows that the concentrations of Zn, Cd and Pb in Balsall Heath were higher than the mean and that Pb was the maximum value found. These results drove the Coventry MPC study, the results from which are discussed below.

5.2.2. Coventry

Apart from Ni, the highest concentrations of heavy metals associated with MPCs in Coventry are found within the ring road (Fig. 5a–e).

One particular junction, associated with samples 36, 38 and 39 in the far east of the sampling area, has one of the hotspots common to all metals except Pb, although sample 39 does have a concentration of >100 μg g^{-1} Pb. The distribution of Ni is the opposite of the other four metals, the highest values being located outside of the ring road. This is reflected in its significant ($P = 0.01$) negative correlation with Pb, and the significant difference it exhibits when concentrations within and outside the ring road are compared using the two-sample Kolmogorov–Smirnov test (Table 5).

The properties of Ni mean that it is resistant to corrosion (Street and Alexander, 1994). It therefore has widespread uses from the production of office furniture to the protection of motor vehicle bodies. It is also produced during the wear of sinterized materials used in car oil pumps along with Cu and Mo (De Miguel et al., 1997). The highest values for Ni (all >200 mg kg^{-1}) are found in the south and west, outside the ring road (Fig. 4e), but no particular factor can be

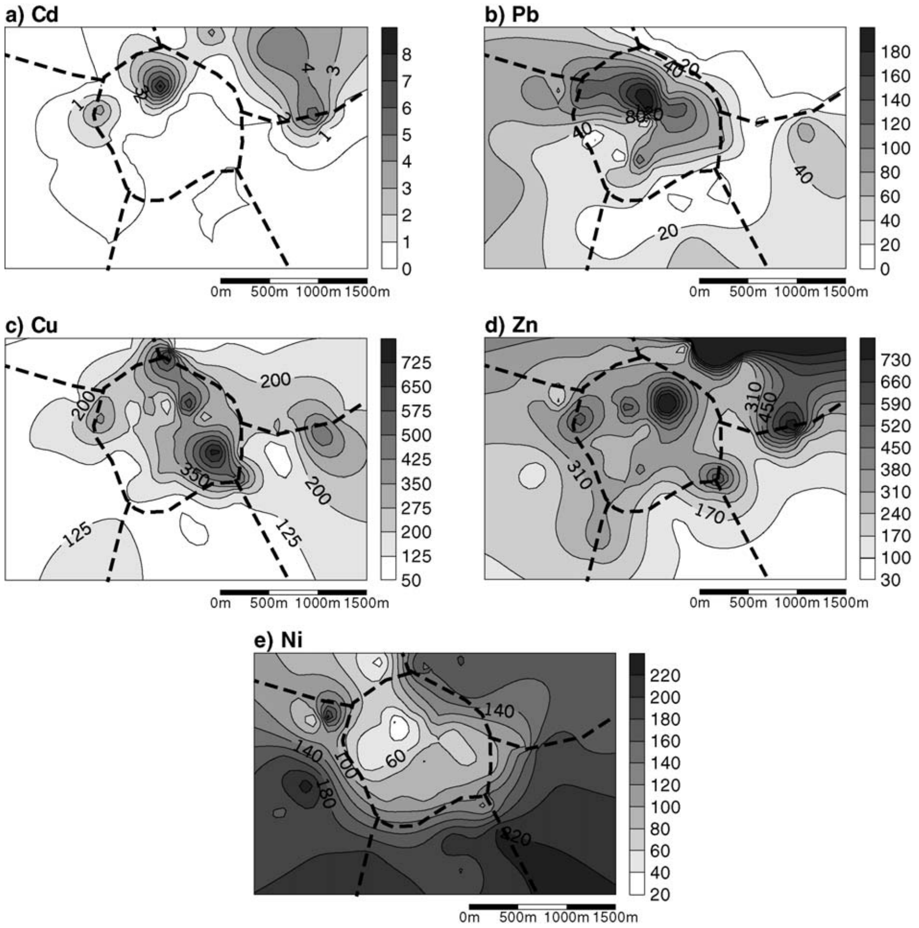

Fig. 5. Spatial distribution of heavy metals (μg g^{-1}) in the street dusts of Coventry. (a) Cd, (b) Pb, (c) Cu, (d) Zn and (e) Ni.

Table 5
Two-sample Kolmogorov–Smirnov test results to determine significant differences in heavy metal concentrations

Metal element	Pb	Cd	Cu	Zn	Ni
(1) The Birmingham database compared with the Coventry database					
Significance	0.063	0.019	0.91	0.003	0.0
P	NS	0.05	NS	0.01	0.01
(2) Samples from within and outside the ring road					
Birmingham					
Significance	0.951	1.0	0.002	0.001	0.042
P	NS	NS	0.01	0.01	0.05
Coventry					
Significance	0.005	0.994	0.192	0.007	0.0
P	0.01	NS	NS	0.01	0.01
(3) Samples in close proximity to green spaces					
Birmingham					
Significance	0.42	0.839	0.381	0.041	0.147
P	NS	NS	NS	0.05	NS
Coventry					
Significance	0.363	0.294	0.702	0.584	0.111
P	NS	NS	NS	NS	NS
(4) Samples in close proximity to main roads					
Birmingham					
Significance	0.36	0.48	0.051	0.211	0.11
P	NS	NS	NS	NS	NS
Coventry					
Significance	0.037	0.999	0.939	0.439	0.002
P	0.05	NS	NS	NS	0.01
(5) Comparison of samples in residential and industrial areas (Birmingham only)					
Significance	0.229	0.788	0.002	0.001	0.559
P	NS	NS	0.01	0.01	NS

NS = not significant, where $P = 0.05$ or 0.01 the significant difference is at the 5% and 1% levels respectively.

attributed to these values. Many authors associate Cd, Pb and Zn with traffic movements (Ellis and Revitt, 1982; De Miguel et al., 1997; Jiries et al., 2001) and the two-sample Kolmogorov–Smirnov test discussed below highlights both Ni and Pb as being significantly higher near main roads, but no explanation can be given for Ni being higher outside of the ring road.

The dust databases were subjected to the two-sample Kolmogorov–Smirnov test to determine whether there was any significant difference between the distributions of heavy metal concentrations within groups of samples located in/or outside the ring roads or whether proximity to green spaces or main roads lead to any differences. The two-sample Kolmogorov–Smirnov test is used with non-parametric data to test the absolute differences between two sets of samples (Trufford and McKellar, 1999). When the difference is large, the two samples are considered to be different and the null hypothesis, that the two samples are taken from the same underlying distribution, is rejected. In this study, the hypothesis was rejected at $p \leq 0.05$. The two-sample Kolmogorov–Smirnov test was also used to compare residential with industrial areas in Birmingham, but not in Coventry, where most of the industry is located outside the study area.

5.3. Significance of sample location

Table 5 shows the results of comparing subsets of samples using the two-sample Kolmogorov–Smirnov test. Cd, Zn and Ni show significant differences between Coventry and Birmingham when all of the databases are compared. Individually, the city's ring roads appear to impact their environments rather differently. Zn and Ni in both Coventry and Birmingham show significant differences at the 0.01 level, and at both sites, there is no significant difference between Cd within or outside the ring road. However, there is a significant difference between Pb in the two subsets associated with Coventry, but not Birmingham, and the reverse is true of Cu, with a significant difference in Birmingham, but not Coventry. Green spaces do not seem to impact on the distribution of the heavy metals apart from Zn in Birmingham. Close proximity to main roads does not lead to any significant differences in any of the heavy metals in Birmingham, but there are significant differences between the two subsets for Pb and Ni in Coventry. Lastly, the comparison of subsets of samples located within residential or industrial areas in Birmingham shows significant differences in the distributions of Cu and Zn only at the 0.01 significance level.

5.4. Assessment of hazard

Comparison of the concentrations obtained from the two studies with "trigger concentrations" (Table 3) indicates that both mean and maximum values for Pb are well below trigger concentration at both sites (ICRCL, 1983).

This may well be a result of the introduction of unleaded petrol. The values are well below those reported by Davies et al. (1987) (see Table 1), but may well represent a further decline in Pb levels due to the continued use of unleaded fuels. While the mean values for Cd obtained for both studies are below trigger concentrations, maximum values are more than four times trigger levels in Birmingham and nine times trigger levels in Coventry. Mean Zn, Ni, and Cu are all well above trigger concentration in both studies. Although MPCs may provide a safe haven for pedestrians when crossing the road in Coventry, they may be exposed to high levels of heavy metals while waiting for the signal to allow them to cross safely. While the values for dusts in close proximity to Coventry MPCs are high, they are lower than concentrations obtained for street dusts in Birmingham apart from Ni. As discussed in the sampling protocol, Harrison et al. (1985) estimated that the dust collecting in the gutters represented about 10% of the total output from motor vehicles with concentrations increasing towards the centre of the road. On the one hand, metal concentration may therefore be expected to rise as the pedestrian crosses the road, on the other hand, particles that are small enough to be entrained into the air and be inhaled would be expected to carry the highest concentrations of heavy metals associated with them. The figures presented here may therefore only be conservative, but still represent high values, exceeding trigger concentration.

The values used to assess potential hazard are based on a total acid digestion of the dust. The heavy metals associated with dust particles may not all be bioavailable, thus the following section discusses results from a limited number of samples taken from Coventry which have been sequentially digested to assess speciation, and hence give an indication of bioavailability. This is a preliminary study which is intended to extend to Birmingham in the future.

5.5. Assessment of bioavailability in Coventry street dusts

Table 6 shows the results of the study of metal speciation in Coventry street dusts.

It was found that very little of any of the heavy metals were bound to the readily available exchangeable sites, although Cd (15.2%) and Ni (9.8%) had one sample each with appreciable percentages of heavy metal in the exchangeable form. However, Cd was found mainly in association with carbonates and organic matter or sulphides as well as the exchangeable form, and this made it potentially the most bioavailable element, in agreement with many studies. Ni and Pb were found to be only associated with organic matter or sulphides making them the least easily available, Ni also had the highest percentage in the least available residual form (33%). Five of the samples analysed for Zn and Cu were bound to organic matter or sulphides, but the remaining two Zn samples were associated with carbonates and hence relatively more easily released in comparison with the two Cu samples which were found bound to Fe and Mn oxides. Thus the order of bioavailability in this study differed slightly from some of the other studies: Cd>Zn>Cu>Pb>Ni (see Introduction). Should environmental conditions change, principally in terms of Eh and pH, there is the potential for heavy metals to be released, in particular Cd and possibly Zn. Urban areas undergo constant change due to continuing construction and demolition work, and therefore this scenario is a distinct possibility in the future. Any metals released in this way would then be flushed through the drain network into streams and other water courses.

Table 6

Sequential digestion of street dusts from Coventry (%) $n = 7$

Sample no.	Element	Fraction				
		1	2	3	4	5
1	Cd	15.2	50.1	19.3	15.4	0.0
2		7.7	76.9	0.0	7.7	7.7
3		0.0	28.0	12.0	60.0	0.0
4		1.8	7.0	0.6	90.6	0.0
5		0.0	37.9	6.89	55.2	0.0
6		2.6	36.8	13.2	47.4	0.0
7		0.0	45.0	35.0	20.0	0.0
1	Cu	0.0	1.5	85.3	11.2	1.0
2		1.6	17.3	61.4	18.1	1.6
3		2.2	0.0	7.0	89.2	1.6
4		0.1	0.0	7.7	91.8	0.4
5		0.0	11.7	11.4	75.1	1.8
6		0.13	4.4	11.5	83.3	0.7
7		0.0	20.5	33.3	44.9	1.3
1	Ni	9.8	33.4	0.0	40.1	16.7
2		0.0	26.7	0.0	40.0	33.3
3		3.5	6.9	0.0	79.3	10.3
4		2.9	5.7	4.3	82.9	4.3
5		1.6	8.1	3.2	82.3	4.8
6		1.4	5.6	9.9	76.1	7.0
7		0.0	18.2	22.7	50.0	9.1
1	Zn	2.5	64.1	12.2	20.5	0.7
2		1.5	40.1	19.1	37.2	2.1
3		0.12	22.2	6.5	70.5	0.7
4		6.2	17.4	12.1	64.3	0.05
5		0.0	18.4	5.1	75.8	0.6
6		0.5	21.1	8.2	69.6	0.6
7		0.4	38.5	11.3	48.7	1.1
1	Pb	0.4	21.6	28.5	47.0	2.6
2		0.0	23.7	26.9	46.8	2.6
3		1.0	2.9	15.5	77.7	2.9
4		0.7	5.3	6.2	87.2	0.6
5		0.0	20.9	15.7	62.3	1.1
6		0.14	10.9	5.5	83.3	0.2
7		0.3	14.2	20.4	65.1	0.0

Where fraction 1 = exchangeable, 2 = Carbonate bound, 3 = Fe/Mn bound, 4 = organic matter bound and 5 = residual.

6. Conclusions

1. Both studies found high heavy metal concentrations with the greatest variations in concentration exhibited by Zn and Cu e.g. Zn in Birmingham street dusts varied from 81.3 to over 3000 mg kg^{-1} and Cu varied from 16.4 to over 6600 mg kg^{-1} (Table 3).
2. Previous studies have suggested that the residence times of street dust are short (e.g. Allott et al., 1990). While the residence times of street dust in Coventry and Birmingham are not known, nonetheless, it appears to retain evidence of historical contamination by the incorporation of eroded, contaminated soil. Thus, the brass and coin making activities to the northwest of Birmingham were identified, in particular by Cd, but on closer inspection of the data, also by Zn and Cu.
3. The heavy metal concentrations in the street dusts of Birmingham in comparison to Coventry were shown to be significantly different apart from Cu. However, individual metals behaved slightly different in response to the proximity of main roads, green spaces and the positions of sampling sites relative to the ring roads.
4. The success of the introduction of unleaded petrol was shown in the lowering of values for Pb by almost one third in Birmingham in comparison with studies undertaken by Davies et al., 1987. While Birmingham Pb concentrations were, as a consequence, below ICRCL (1983) trigger concentration, other metals exhibited concentrations that were well above the ICRCL (1983)

trigger concentration. In the assessment of dusts located near MPCs in Coventry, mean values for Pb and Cd were below trigger levels, but the maximum value for Cd was nearly three times its trigger level. This may have health consequences for pedestrians waiting to cross the road.

5. In a limited assessment of the potential bioavailability of metals bound to street dusts, it was found that very little was in the exchangeable and most available of fractions. Very little metal was found in the residual form, which means that should environmental conditions such as Eh or pH change, there is the potential for metals, in particular Cd, to be released.
6. Further work is needed not only to assess the spatial distribution of metals in street dusts but also to examine variation at a smaller scale, e.g. within an individual grid square. In particular, where this study has identified a possible source for elevated concentrations e.g. the Soho Foundry, then more intensive sampling of that area needs to be carried out.

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