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Trace Elements in Street and Household Dusts in Amman, Jordan

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This research aims at quantifying the concentrations of heavy metals within the home environment in Amman, the capital city of Jordan, and to compare the total concentrations of indoor dusts to that of exterior dusts and soils. Housedust samples were collected from different zones of Amman. Street dust samples and garden soil samples were collected in the immediate vicinity within 10–50 m of each residence. The geometric mean concentrations of metals in the household dust were Pb, 169 mg/kg; Cd, 2.92 mg/kg; Zn, 1985 mg/kg; Cu, 133 mg/kg; Cr, 66 mg/kg; Co, 21 mg/kg; Ni, 31 mg/kg; Mn, 284 mg/kg; Be, 3.0 mg/kg; Ba, 43 mg/kg; B, 697 mg/kg and Al, 1441 mg/kg. Comparisons of household dust, garden soil and street dust were based on the same particle size fraction. Results showed housedust samples to contain higher concentrations for Pb, Zn, Cr, Ni, Cd, Cu and B, than either street dust or garden soil samples. However, the differences between Pb and Cr levels in the three different sample categories were insignificant. Enrichment factor calculations and the enrichment factor ratios indicated that patterns of enrichment of indoor dust differ from that of exterior dusts.

Keywords Heavy metals, housedust, street dust, soil, ICP-OES, enrichment factors

1. Introduction

Heavy metals may come from many different sources in urbanized areas, including vehicle emissions, industrial discharges and other activities (Harrison *et al.*, 1981; Gibson and Farmer, 1986). Heavy metals can accumulate in topsoil from atmospheric deposition by sedimentation, impaction and interception. Metals are usually non-degradable and there is no known homeostasis mechanism for them. Thus, any high levels of heavy metals will threaten biological life. Laboratory studies show that manganese, cadmium, copper, lead, and zinc are initiators or promoters of carcinogenic activities in animals (Nriagu, 1988). Urban survey data indicate wide variations in metal concentrations of dust and soil in different activity areas within a residence, amongst different residences within a community, and amongst different communities (Gulson *et al.*, 1995; Lanphear *et al.*, 1998; Mielke and Reagan, 1998; Meyer *et al.*, 1999; Morawska and Salthammer, 2003), highlighting the need for more representative, site-specific data to expand residential exposure assessments.

In recent years, a number of authors have suggested that elevated levels of metals in household dust, garden soil and urban street dust pose a potential human health hazard (Mielke and Reagan, 1998; Matte, 1999; Meyer *et al.*, 1999; Lioy *et al.*, 2002; Lynch *et al.*,

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2000; Butte and Heinzow, 2002; Greenpeace 2003; Takaro *et al.*, 2004). Common housedust contains a mixture of particulates from indoor aerosols, pesticides, solvents, fungal spores, soil tracked in by foot traffic, and traces of metals (EPA, 1997; Lioy *et al.*, 2002; Maertens *et al.*, 2004). Together, they form an invisible toxic hazard that scientists have only just begun to study. The precise composition of a housedust sample is a function of numerous factors including environmental and seasonal factors, indoor and outdoor source activities, heating sources, and ventilation (Maertens *et al.*, 2004). The penetration of outdoor particles into the indoor environment has been shown to be a significant source of indoor particles (Abt *et al.*, 2000; Morawska *et al.*, 2001; Morawska and Salthammer, 2003).

The present study was undertaken to determine total concentrations of a variety of metals of environmental concern, in urban dusts collected from Amman, the capital city of Jordan, and to compare the total concentrations of indoor dusts to that of exterior dusts and soils. To achieve this goal, total element concentrations were determined in household dusts, garden soil and street dust samples from different sectors in Amman.

2. Methods

2.1. Sample Collection

The climatic conditions in Jordan are characterized by long, hot, dry summers and short, cool, rainy winters. The weather is rainy from November to mid-April and very dry for the rest of the year. Therefore, sampling was carried out in the second week of May 2005 to avoid the influence of weather conditions, such as rain or strong wind. Housedust samples were collected from a total of 20 residences selected at random from five different zones of Amman. They were Abdali, City Center, Basman, Ras Al-Aein, and Al-Yarmouk. In each of the sampling areas, only those housing estates that were close to roadways were chosen for sampling. Samples were collected from private dwelling units built between 1950 and 2000. Out of the total of 20 dwellings, 35% (7) were built prior to 1980. Although dwellings participated in this are scattered over a wide area, they are all located in congested areas. The indoor dust samples were collected using vacuum cleaners. To avoid cross-sample contamination, new vacuum cleaner bags were provided for the sample collection and the vacuum cleaners were cleaned thoroughly between each sample. The dust was then transported in resealable plastic bags and stored for subsequent sample preparation and analysis. Sampling locations are shown in Figure 1.

Street dust samples and garden soil samples (20 samples each) were collected in the immediate vicinity within 10–50 m of each residence. Street-dust samples were swept using a clean plastic brush and dust pan. Briefly, the dust samples were collected from both sides of the road directly adjacent to each residential property. A composite sample out of the two (collected from both sides of the road) was obtained. An area generally ranging from 0.5 to 1.0 m^2 was swept in order to obtain a sufficiently large sample for analysis and to help overcome the problem of localized spatial variation. A clean stainless steel trowel was used to collect and composite the top 10 cm of garden soil in the yard of each household. The samples were placed in clean polythene bags and then sealed and labeled.

2.2. Sample Preparation and Analysis

In the laboratory, samples were sieved through 200-μm polystyrene screen, and then oven dried at 35°C for 3 days. The dried samples were then homogenized with a mortar and

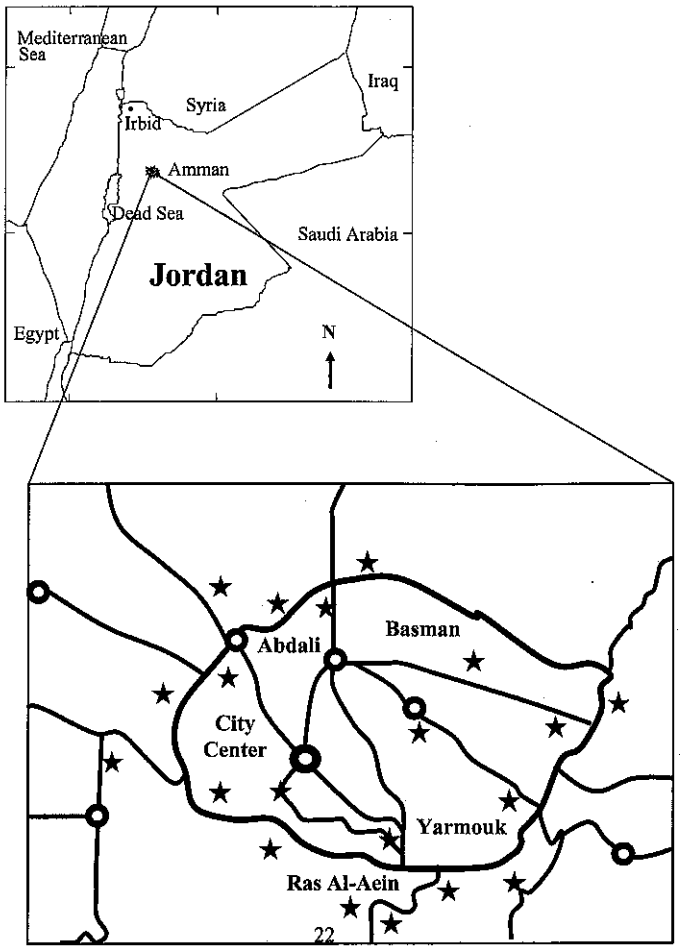

Figure 1. Map of the sampling area showing sampling locations (not to scale).

a pestle. The procedure described by Rasmussen *et al.* (2001) was followed to digest the samples with some modifications. Approximately 0.5 g of the sample was transferred into a Teflon 250 ml beaker. About 20 ml of high purity concentrated HNO_3 and 5 ml HF were added and allowed to sit overnight at ambient temperature. Street dusts required the addition of perchloric acid 0.4 ml at this stage to dissolve an acid-resistant organic component. After slow evaporation to near dryness, nitric acid was added (2 ml) and the solutions were evaporated again to about 0.5 ml. The digest was cooled and diluted with deionized water up to 50 ml and stored in plastic bottles. Concentrations of Pb, Cd, Cu, Zn, Mn, Co, Ni, Cr, Be, Ba and Al were determined by ICP-AES (Varian, Vista-MPX simultaneous ICP-OES), equipped with a 1.4 kW power, and axially viewed plasma.

2.3. Quality Control and Quality Assessment

The minimum detection limits (MDL) of the digested sample solution were estimated as the concentration that produced three times the average background intensity at the respective wavelengths selected for each element during calibration runs. The calculated values are

Table 1
Recovery and precision based on two standard reference materials (NIST-2704 and NIST-2710) for ICP-OES analyses

		NIST-2704			NIST-2710		
Element	MDL[a] (mg/kg)	Found[b] (mg/kg)	RSD[c] (%)	Recovery (%)	Found (mg/kg)	RSD (%)	Recovery (%)
Al	20	56.1	9.2	92			
B	30						
Ba	2	394	7.3	95	339	7.8	97
Be	2						
Cd	0.6	3.41	2.4	99	19.1	2.1	98
Co	3	13.6	6.2	96	8.4	11.5	92
Cr	3	128	8.4	95	19.5	8.8	103
Cu	4	96.9	2.1	98	2830	4.2	98
Mn	5	548	4.5	99			
Ni	3	44.5	6.3	101	12.2	6	102
Pb	6	156	3.8	97	5380	4.7	95
Zn	2	446	4.6	102	6450	5.8	104

[a]MDL: is the minimum detection limit, concentrations were above MDL for all elements in all samples except for Cd in 8 samples, for which half of the MDL value were assigned. In addition Al in SRM-2710 was below detection limit.
[b]Found: is the average concentration for five replicates.
[c]RSD: is the relative standard deviation for five replicates.

listed in Table 1. Except for Be and Cd, concentrations of all measured elements in all samples were at least ten times higher than MDL. However, this ratio was six for Be and less than three for Cd. Cadmium was below detection limit in eight samples and, therefore, half of the MDL value was assigned for these samples.

The accuracy and precision of the analysis results were checked by periodic analysis of Standard Reference Materials (SRM) obtained from the National Institute of Standards and Technology (NIST). Two SRMs were used; SRM-2704 (Buffalo river sediment) and SRM-2710 (Montana soil) and digested using the same procedure followed for the samples and analyzed along with samples. The results for SRMs analysis were seen to be acceptable and are given in Table 1. As shown, observed concentrations were within ±5% of certified values in analyzed SRMs for Ba, Cd, Zn, Cr, Cu, Mn, Ni and Pb and within 10% for Al and Co. Except for nickel, analytical reproducibility was better than 10% relative standard deviation (RSD) for all of the measured elements (Table 1). The RSD for nickel in the second standard reference material (SRM-2710) was >10%, because the concentration is close to the minimum detectable limit (MDL) listed in Table 1.

3. Results and Discussion

3.1. Differences Between Indoor and Exterior

Statistical summaries for concentrations of the 12 elements (Pb, Cd, Cu, Zn, Co, Cr, Mn, Ni, Be, Ba, B and Al) measured in the housedust, street dust and garden soil dust are

Table 2
Total element concentrations (mg/kg dry weight) in housedust of Amman residences (n = 20)

	Average	G. Mean	Median	Min	Max	SD
Al	2330	1441	1510	213	11374	2865
B	980	697	879	25	2629	658
Ba	85	43	58	2	294	88
Be	3.3	3.0	2.7	1.6	6.3	1.6
Cd	4.46	2.92	2.81	0.78	23.75	5.80
Co	23	21	18	11	67	15
Cr	77	66	71	23	151	40
Cu	160	133	139	49	499	114
Mn	304	284	319	131	510	109
Ni	47	31	42	2	119	33
Pb	206	169	173	65	518	141
Zn	3104	1985	1868	420	12441	3407

given in Tables 2–4. The data sets are positively skewed; therefore geometric mean and median metal concentrations represent amounts more accurately than arithmetic means. Consequently, geometric means and medians are presented in the tables in addition to arithmetic means, standard deviations and ranges.

A comparison of the total elemental concentrations summarized in Tables 2-4 indicate that housedust samples contain higher concentrations of some elements, including lead, zinc, chromium, nickel, cadmium, copper and boron, than either street dust or garden soil samples. The geometric mean concentration of lead is 169 mg/kg and is slightly higher than 141 and 160 mg/kg found for garden soil and street dust, respectively. Geometric mean concentrations of Pb in housedust samples were higher than all corresponding samples in

Table 3
Total element concentrations (mg/kg dry weight) in garden soil of Amman residences (n = 20)

	Average	G. Mean	Median	Min	Max	SD
Al	4766	1966	1293	349	24196	7377
B	103	84	74	35	225	67
Ba	513	193	255	6	1947	633
Be	8.1	7.2	6.3	4.2	16.3	4.5
Cd	0.69	0.24	0.35	0.01	2.48	0.82
Co	77	57	45	23	236	67
Cr	50	44	38	18	123	30
Cu	49	37	27	11	154	43
Mn	309	279	355	128	570	138
Ni	73	18	16	2	481	140
Pb	195	141	147	16	406	134
Zn	299	182	153	45	1332	374

Table 4
Total element concentrations (mg/kg dry weight) in street dust of Amman (n = 20)

	Average	G. Mean	Median	Min	Max	SD
Al	2837	1429	2465	46	17592	3500
B	393	151	126	24	1913	559
Ba	328	124	101	7	1932	475
Be	5.2	5.1	5.3	2.7	8.0	1.4
Cd	0.78	0.43	0.44	0.01	3.22	0.85
Co	64	55	65	17	162	35
Cr	91	52	54	16	1010	189
Cu	315	127	118	26	3883	750
Mn	262	244	220	142	533	108
Ni	75	38	46	2	258	73
Pb	199	160	143	52	614	152
Zn	877	386	335	87	6848	1518

garden soil samples and in more than 70% of the street dust samples. However, RSD values for lead in the three different categories are close to each other, indicating that lead is almost uniformly distributed. No significant differences between Pb levels in different categories were observed. This was confirmed statistically using paired two samples *t*-test.

The geometric mean cadmium concentration in housedust (Table 2) is over 12 times higher than that of garden soil (Table 3), and six times higher than that of street soil (Table 4). The RSD value for Cd in housedust samples is at least five times higher than RSD values for Cd in garden soil and street dust samples. This reveals that levels of Cd in housedust are highly variable. Differences between Cd levels in housedust and garden soil and street dust were highly significant ($P < 0.005$).

Similarly, the geometric mean B, Zn and Cr concentrations in housedust are over 8, 11 and 1.5 times higher than that of garden soil, and 4, 5 and 1.5 times higher than that of street dust, respectively. Differences between B and Zn levels in the three different categories were significant ($P < 0.01$). However, Zn concentrations in housedust ranged from 420 to 12000 mg/kg, and the RSD was 7407, which reflects the large variability in Zn levels. Housedust chromium concentrations slightly exceeded street dust and garden soil chromium concentrations in most of the samples. The differences between Cr levels in the three categories were insignificant at $p < 0.05$.

The geometric mean concentrations of Cu and Ni were two to three times higher than the geometric mean concentrations in garden soil and close to that in street dust soil. However, levels of Cu and Ni in street dust show large variability as revealed by the large RSD values; 759 and 189 for Cu and Ni, respectively. The only significant difference in the levels of Cu and Ni in the three categories was between levels of Cu in housedust and street dust ($P < 0.005$). On the other hand, however, concentrations of Al, Ba, Be, Co and Mn in garden soil were higher than in housedust and street dust. Rasmussen *et al.* (2001) have attributed the increased concentrations in garden soil relative to that in street dust to several factors. These are losses of soluble species from street dust by run-off during municipal street cleaning, greater attenuation in garden soils due to the higher organic matter content of the soil matrix, wash-off of settled dust, paint chips, other particulate matter from houses, and leaching of soluble species from exterior wall and roof materials.

Table 5
Comparison with geometric means of other studies for metal concentration in household dust (mg/kg dry weight)

Element	Amman (Jordan) This study	Sydney (Australia)[a]	Ottawa (Canada)[b]	Taejon (Korea)[c]	Bahrain[d]*	Christchurch (New Zealand)[e]
Cr	66.5	64.3	75.4		11	
Cd	2.92	1.9	4.4	2.6	1.9	4.24
Cu	133	103	170	128–168		165
Ni	47	15.6	53.6		10	
Pb	169	85.2	232	80–178	517	573
Zn	1985	437	628	320–491	202	10400
Mn	283.6	54	260			
Al	1441.2		24281			
Ba	42.7		454			
Be	3.0		0.53			
Co	20.5		8.4			

[a]Chattopadhyay *et al.* (2003).
[b]Rasmussen *et al.* (2001).
[c]Kim *et al.* (1998).
[d]Akhter and Madany (1993).
[e]Kim and Fergusson (1993).
*Arithmetic means are reported.

3.2. *Comparisons with Literature Data*

Comparison of the obtained data with the literature is one of the essential steps in order to know the extent of contamination by these metals. In addition, comparing the data with data obtained from resembling areas may help in finding out the unusual results, which could be due to particular analytical problem. Observed concentrations of elements are compared with those found by others in other cities and presented in Table 5. We should mention here that not all of the studies mentioned in Table 5 have used the same particle size. The data in this table reveals that geometric mean concentration of Pb in the household dusts of Amman was 169 mg/kg (minimums = 65 mg/kg, maximums = 518 mg/kg) and is about 3 times lower than those reported for Bahrain and Christchurch and 1.5 times lower than those reported for Ottawa (Akhter and Madany, 1993; Kim and Fergusson, 1993; Rasmussen *et al.*, 2001). Arithmetic means have been reported for Al-Bahrain, which is usually higher than geometric mean. Moreover, the housedust in Christchurch was collected by suction onto a glass-fiber filter using a small vacuum pump. The type of dust collected consisted of very fine silt/clay size particles, which generally have higher element concentration values than larger fractions (Gulson *et al.*, 1995). On the other hand, geometric mean concentration of Pb in the household dusts of Amman was about two times higher than those reported for Taejon (Korea) and Sydney (Australia) (Kim *et al.*, 1998; Chattopadhyay *et al.*, 2003).

Geometric mean concentrations of Cu and Cd in the household dusts were 133 mg/kg (minimums = 49 mg/kg, maximums = 499 mg/kg) and 2.92 mg/kg (minimums = 0.78 mg/kg, maximums = 23.75 mg/kg), respectively. These levels show similar trend to Pb, in which they were lower than those reported for Ottawa (Canada) and Christchurch

(New Zealand), and higher than those reported for Sydney and Taejon (Korea). The use of smaller particle sizes could be the reason for higher Cu and Cd concentrations in Christchurch. Geometric mean concentrations of Zn in the household dusts of Amman was 1985 mg/kg (minimums = 420 mg/kg, maximums = 12441 mg/kg). This concentration is five times lower than those reported for Christchurch (New Zealand) and much higher than all those reported for Ottawa, Sydney, Taejan and Bahrain.

The geometric mean concentrations of Cr and Ni in housedust of Amman appear to be slightly lower than those for Ottawa and higher than those for Sydney and Bahrain. Concentrations of the other metals were compared with those reported for Ottawa and were either close to them (Mn, Co and Be) or much lower than them (Al and Ba).

3.3. Enrichment of Measured Elements

Enrichment factors (EF) can be calculated to show the degree of enrichment of a given element in the dust sample compared to the relative abundance of that element in crustal material. The factor is calculated using the following equation (Lehame *et al.*, 1992):

$$EF = \frac{(C_x/C_{Al})_{sample}}{(C_x/C_{Al})_{crust}} \tag{1}$$

where $(C_x/C_{Al})_{sample}$ is the ratio of concentration of an element X in mg/kg to that in sample and $(C_x/C_{Al})_{crust}$ is the same ratio in crustal material obtained from Mason's (1966) compilation for trace elements in earth crust. Elements that have other sources than crustal dust have enrichment factors higher than unity. An enrichment factor less than 10 may be considered to represent natural levels. A value greater than 10, on the other hand, is considered to indicate contamination by that metal. Wiersma *et al.* (1987) point out that enrichment factor values greater than 10 are taken to indicate contamination by noncrustal sources.

The data in Table 6 show the crustal enrichment factors of measured elements in the housedust, street dust and garden soil samples. These data place the urban data into the context of natural background concentrations in Amman, indicating that, for many elements, housedust concentrations exceed natural concentrations. As we can see, all metals

Table 6
Enrichment factor values for measured elements

	Garden		House		Street	
Element	Average	G. Mean	Average	G. Mean	Average	G. Mean
Al	1	1	1	1	1	1
Cd	100	30	1175	419	220	62
Co	184	117	63	46	286	125
Cr	31	25	50	38	62	31
Cu	57	44	196	136	464	131
Mn	17	13	23	16	38	14
Ni	216	64	663	232	1941	295
Pb	961	479	1074	732	721	526
Zn	364	205	4071	1602	1162	314

studied are enriched in the housedust. This result is in agreement with the results of other studies, where it has been assumed that the phenomenon is caused by the selective (relative) enrichment of the finer (heavy metal rich) dust particles in the housedust. The selective importation of small particles (on footwear or as aerosols) and the preferential removal of the coarser fractions during cleaning have been suggested as two mechanisms by which this might occur (Sayre and Katzel, 1979; Thornton *et al.*, 1985).

Lead, Cd, Zn, Cu and Ni in housedust samples have enrichment factors greater than 100, which must be considered to be indicative of gross contamination. Enrichment factors lower than those observed for housedust and higher than 100 were also obtained for lead and cadmium in street dust and garden soil samples. These data suggest widespread contamination by human sources. Cobalt was highly enriched in garden soil and street dust samples (EF > 100) and moderately enriched in housedust samples (EF = 50). Manganese levels, on the other hand, are slightly enriched in all samples, which is an indication of crustal contributions.

The large variation in the EF values for the same element in the three different sample categories indicates that the pattern of enrichment of indoor dust differs significantly from that of garden soil and street dust. For instance, the house-to-garden EF ratios were 12.3, 11, 8.3 and 1.2 for Cd, Zn, B and Pb, respectively. However, the street-to-garden EF values were 6.8, 5.1, 4.6 and 0.4 for Cd, Zn, B and Pb, respectively. The penetration of outdoor particles into the indoor environment has been shown to be a significant source of indoor particles (Riley *et al.*, 2002; Abt *et al.*, 2000; Morawska *et al.*, 2001). Outdoor dust from different sources (such as soil, forest fire emissions, fossil fuel combustion, and volcanic debris) are usually carried in by foot traffic. However, in the indoor environment, additional dust sources such as skin, hair, mites, rubber of carpet underlays, fibers from clothing and furnishings, cooking emissions, heating emissions and cigarette smoke are present (Morawska and Salthammer, 2003). Consequently, the differences in the patterns of enrichment mentioned above could be explained by the incorporation of the indoor and outdoor dusts within the house environment.

One of the important reasons for the enrichment of indoor dust relative to outdoor dust is the influence of the particle size. Indoor dust particles are usually finer (richer in heavy metals) than outdoor dust due to the selective importation of small particles and the preferential removal of the coarser fractions during cleaning (Sayre and Katzel, 1979; Thornton *et al.*, 1985). Johnson *et al.* (1982), who used scanning electron microscopy and X-ray energy spectroscopy to characterize individual particles of housedust, found that the highest concentrations of Pb and Cd were present in the finest particle size ranges. All these reasons may explain the enrichment of Pb and Cd in housedust relative to outdoor dust.

The data in Table 6 reveals that Zn in housedust sample is highly enriched compared to street dust or garden soil samples. Kim and Fergusson (1993) have found that roof type and the existence of rubber underlay are the two important factors affecting Zn levels in housedust. Zinc compounds are used in the vulcanization process of rubber production. Therefore, the use of galvanized-iron roofing and the presence of carpet in the surveyed houses are among the significant sources for the observed high levels of Zn in the collected housedust samples. In addition, houses surveyed in this study are located in congested areas and near roadways. In these areas, outdoor dust is expected to contain high levels of Zn resulting from the wear and tear of tires. Therefore, contribution from the outdoor dust is also expected to be a significant source for the observed high levels of Zn. In this occasion we should mention that accurate identification and description of the possible sources contributing to the observed metal concentrations in housedust needs further detailed investigations.

Style of heating is one of the significant factors affecting the levels of certain metals in household dust with higher metal concentrations in coal and other fossil fuels heated houses (Meyer *et al.*, 1999). Rasmussen *et al.* (2001) found that housedust of electrically heated houses tends to be higher in both lead and mercury content than housedust of gas- or oil-heated houses. In Jordan, the use of coal and gas is very rare. The main oil that is generally used for heating is diesel. Two types of heaters are generally used and both of them are fueled mainly by diesel. The first one is based upon the use of sophisticated burners installed in the basement of the building and bumping the hot water through radiators to the whole house. These furnaces have external flues where exhaust gases vent to the outside. The second type of heaters, which is common in poor regions, is based upon the use of a metal furnace fueled by diesel installed in the living space. As these heaters are installed in the living space, the flue where the exhaust gases vent to the outside are also internal, and they allow warmed air and smoke to escape from the system into the house. This style of heating is believed to increase the indoor-dust metal concentrations and loading rates. To validate this argument, eight housedust samples out of twenty were collected from houses that are using the second style of heating. The geometric mean concentrations of Pb, Ni and Zn in houses using the second style of heating were 249, 515 and 2270 mg/kg, respectively, compared to 136, 231 and 1843 mg/kg in houses using the first style of heating. These levels represent approximately two-folds increase in concentrations of these elements. However, no significant differences between concentrations of other measured elements were observed.

3.4. Relationships Between the Metals

Binary correlations between measured metals have been computed in order to obtain some information on the sources of metals in the collected soil and dust samples. The greatest correlation between metal concentrations in housedust samples (mg/kg) occurs for cobalt and aluminum ($r = 0.90$, $P < 0.001$), copper and aluminum ($r = 0.72$, $P < 0.001$), and cobalt and copper ($r = 0.70$, $P < 0.001$). These highly significant correlations may indicate that these metals share a common source. Moderate correlations ($r = 0.50$-0.60, $P < 0.01$) were also observed between concentrations of the following pairs: Cd-Be, Ni-Al, Zn-Ni, Pb-Mn, Cr-Be, B-Be and Mn-Be. This may suggest that these metals are partially sharing same sources and/or same enrichment patterns. Lead was also weakly correlated with Cd and copper ($r = 0.40$, $P < 0.05$) and uncorrelated with Zn, suggesting that the main sources of these metals to housedust, and/or their enrichment patterns, differ. It is notable that these correlations are not observed in either the garden soil or street dust data sets, which have distinctly different elemental associations. No significant correlations were observed in comparisons of element concentrations in housedust versus street dust, or housedust versus garden soil.

4. Conclusion

Results of the multi-element analysis of housedust, street dust and garden soil samples collected from Amman, the capital of Jordan, indicated that the indoor housedust contain significantly higher concentrations of Zn, Ni, Cd, Cu and B than the exterior soils. However, the differences between Pb and Cr levels in the three different sample categories were insignificant. Enrichment factor calculations indicated that all metals studied are enriched in both indoor and exterior dusts relative to natural concentrations. However, the house-to-garden EF ratios were significantly different from that of street-to-garden EF values, indicating that patterns of enrichment of indoor dust differ from that of exterior dusts. The use

of metal furnaces fueled by diesel for heating has significantly increased the concentrations of Pb, Ni and Zn in housedust. The identification of the possible sources contributing to the observed metal concentrations in housedust needs further detailed investigations.

References

Abt, E., Suh, H.H., Allen, G., and Koutrakis, P. 2000. Characterization of indoor particle sources: a study conducted in the metropolitan Boston area. *Environ. Health Perspect.* **108**, 35-44.

Akhter, M.S., and Madany, I.M. 1993. Heavy metals in street and house dust in Bahrain. *Water, Air, and Soil Pollut.* **66**, 111-120.

Butte, W., and Heinzow, B. 2002. Pollutants in house dust as indicators of indoor contamination. *Rev. Environ. Contam. Toxicol.* **175**, 1-46.

Chattopadhyay, G., Lin, K.C., and Feitz, A.J. 2003. Household dust metal levels in the Sydney metropolitan area. *Environ. Res.* **93**, 301-307.

Environmental Protection Agency (EPA). 1997. *Exposure Factors Handbook*, National Center for Environmental Assessment, Washington, DC.

Gibson, M.G., and Farmer, J.G. 1986. Multi-step chemical extraction of heavy metals from urban soils. *Environ. Pollut. B*, **11**, 117-135.

Greenpeace. 2003. *Consuming Chemicals: Hazardous Chemicals in House Dust as an Indicator of Chemical Exposure in the Home*. Exeter, UK.

Gulson, B.L., Davis, J.J., Mizon, K.J., Korsch, M.J., and Bawden-Smith, J. 1995. Sources of lead in soil and dust and the use of dust fallout as a sampling medium. *Sci. Total Environ.* **166**, 245-262.

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

Johnson, D.L., Fortmann, R., and Thornton, I. 1982. Individual particle characterization of heavy metal rich household dusts. *Trace Subst. Environ. Health* **10**, 116-123.

Kim, K.W., Myung, J.H., Ahn, J.S., and Chon, H.T. 1998. Heavy metal concentration in dusts and stream sediments in the Taejon area, Korea. *J. Geochem. Explor.* **64**, 409-419.

Kim, N., and Fergusson, J. 1993. Concentrations and sources of cadmium, copper, lead and zinc in house dust in Christchurch, New Zealand. *Sci. Total Environ.* **138**, 1-21.

Lanphear, B.P., Matte, T.D., Rogers, J. *et al.* 1998. The contribution of lead-contaminated housedust and residential soil to children's blood lead levels. A pooled analysis of 12 epidemiologic studies. *Environ. Res.* **79**, 51-68.

Lehame, S., Charleshorth, D., and Chowdhry, B. 1992. A survey of metal levels in street dusts in an inner London neighborhood. *Environ. Int.* **18**, 263-270.

Lioy, P.J., Freeman, N.C.G., and Millette, J.R. 2002. Dust: A metric for use in residential and building exposure assessment and source characterization. *Environ. Health Perspect.* **110** (10), 969-983.

Lynch, R.A., Malcoe, L.H., Skaggs, V.J., and Kegler, M.C. 2000. The relationship between residential lead exposures and elevated blood lead levels in a rural mining community. *Environ. Health* **63**, 9-15.

Maertens, R.M., Bailey, J., and White, P.A. 2004. The mutagenic hazards of settled house dust: a review. *Mutat. Res.* **567**, 401-425.

Mason, B. 1966. *Principles of Geochemistry*. 3rd ed, Wiley, New York.

Matte, T.D. 1999. Reducing blood lead levels. *J. Am. Med. Assoc.* **281**, 2340-2342.

Meyer, I., Heinrich, J., and Lippold, U. 1999. Factors affecting lead cadmium and arsenic levels in house dust in a smelter town in eastern Germany. *Environ. Res.* **81**, 32-44.

Mielke, H.W., and Reagan, P.L. 1998. Soil is an important pathway of human lead exposure. *Environ. Health Perspect.* **106**, 217-229.

Morawska, L., and Salthammer, T. (eds.). 2003. *Indoor Environment: Airborne Particles and Settled Dust*. Wiley-VCH, Weinheim.

Morawska, L., He, C., Hitchins, J., Gilbert, D., and Parappukkaran, S. 2001. The relationship between indoor and outdoor airborne particles in the residential environment. *Atmos. Environ.* **35**, 3463-3473.

Nriagu, J.O. 1988. A silent epidemic of environmental metal poisoning? *Environ. Pollut.* **50**, 139-161.

Rasmussen, P.E., Subramanian, K.S., and Jessiman, B.J. 2001. A multi-element profile of housedust in relation to exterior dust and soil in the city of Ottawa, Canada. *Sci. Total Environ.* **267**, 125-140.

Riley, W.J., McKone, T.E., Lai, A.C., and Nazaroff, W.W. 2002. Indoor particulate matter of outdoor origin: importance of size-dependent removal mechanisms. *Environ. Sci. Technol.* **36**, 200-207.

Sayre, J.W., and Katzel, M.D. 1979. Household surface lead dust: its accumulation in vacant Homes. *Environ. Health Perspct.* **29**, 179-182.

Takaro, T., Krieger, J., Song, L., and Beaudet, N. 2004. Effect of environmental intervention to reduce exposure to asthma triggers in homes of low-income children in Seattle. *J. Exposure Analysis & Environ. Epidemiology* **14**(1), S133-143.

Thornton, I.E., Culbard, S., Moorcroft, J., Watt, M., and Thompson, M. 1985. Metals in urban dusts and soils. *Sci. Technol. Lett.* **6**, 137-144.

Wiersma, G.B., Harmon, M.E., Baker, G.A., and Greene, S.E. 1987. Elemental composition of hylocomium splendens, Hoh Rainforest, Olympic National Park, Washington, USA. *Chemosphere* **16**, 2631.