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Heavy metal distribution in dust from elementary schools in Hermosillo, Sonora, México

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Abstract

The city of Hermosillo, Sonora in northern Mexico was investigated for its heavy metals content. Samples of sedimented dust in roofs from 25 elementary schools were analyzed for their contents of Ni, Cr, Zn, Cd, Co, Ba, V, Pb, Fe and Cu after digestion with nitric acid. The results of the analysis were used to determine spatial distribution and magnitude of heavy metals pollution. The results of this study reveal that heavy metals distribution is different in two areas of the city. The southern area contains higher concentrations of heavy metals than the northcentral area. The mean level of Cd in exterior dust is 5.65 mg kg^{-1} in the southern area whereas the mean level of Cd is 2.83 mg kg^{-1} in the northcentral area. Elevated concentrations of Zn (2012 mg kg^{-1}), Pb (101.88 mg kg^{-1}), Cr (38.13 mg kg^{-1}) and Cd (28.38 mg kg^{-1}) in roof dust were found in samples located near industrial areas. Principal component analysis (PCA) was applied to the data matrix to evaluate the analytical results and to identify the possible pollution sources of metals. PCA shows two main sources: (1) Pb, Cd, Cr and Zn are mainly derived from industrial sources, combined with traffic sources; (2) Fe, Co and Ba are mainly derived from natural sources. V and Ni are highly correlated and possibly related to fuel combustion processes. Enrichment factors were calculated, which in turn further confirms the source identification. Ba and Co are dominantly crustal. Anthropogenically added Cd, Pb, Zn and Cr show maximum enrichment relative to the upper continental crustal component. The distribution of the heavy metals in dust does not seem to be controlled only by the topography of the city, but also by the location of the emission sources.

Keywords: Dust; Roofs; Heavy metals; Mexico

1. Introduction

Particulate matter emitted from the geologic media pose threats to human health and the environment due to expansion of infrastructure development to serve increasing population. Natural particles derive primarily from soil minerals, while anthropogenic particles derive from road construction (asphalt, concrete and road paint), automobiles (tire dust, brake dust), industrial inputs or atmospheric depositions (Adachi and Tainosho, 2005). Apart from the intrinsic geochemistry of earthen dust materials, anthropogenic activities have introduced contaminants in topsoil from atmospheric deposition by sedimentation, impaction and interception (Li et al., 2001). Soil particles are subsequently entrained into the atmosphere as

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dust. Particulate matter, commonly referred to as dust, can range in size from 1 to 10 000 μm. Dust can be generated through civil construction operations, farming activities and vehicle operations on un-surfaced roads. Upon generation, dust can be carried by wind into sensitive environments. Lead and a variety of other metals from automobile exhaust have been found to contaminate roadway and parking site dust sampled in Palermo, Italy (Varrica et al., 2003) and Kayseri, Turkey (Tokalioglu and Kartal, 2006). Key heavy metals are thereby Pb from leaded gasoline, Cu, Zn and Cd from car components, tyre abrasion, lubricants and industrial and incinerator emissions (Markus and McBratney, 1996; Thornton, 1991; Wilcke et al., 1998). Contamination of roadway topsoil material from which dust may be generated by vehicular and wind action is particularly prevalent in developing countries, where most roads are un-surfaced and in some cases leaded gasoline has been in use.

Though there are numerous studies of heavy metal contamination of urban dusts in developed countries, little information is available on heavy metals of urban dusts in developing countries (Banerjee, 2003). Mexican legislation does not consider heavy metal concentration (except by Pb) in dusts. In developed countries, most of these studies of heavy metal contamination in dusts focused on Pb, Cu and Zn (Charlesworth et al., 2003) and little attention has been paid to other trace elements, such as As, Hg, Sb, Cr, Mn, Ag, etc. In addition, the atmospheric particulate standards of most developing countries are based on the mass concentration measurement of the total suspended particles (TSP), including Mexico. Because the relationship between health effects (respiratory and cardiovascular diseases) and TSP levels was found to be much lower than the levels of atmospheric particulates finer than 10, 2.5 or 1 μm (PM10, PM2.5 and PM1, respectively), the ambient air quality standards are currently based on the measurements of PM10 and PM2.5 (USEPA, 2006; Querol et al., 2001). Consequently, most studies are focused on suspended atmospheric particulates (e.g., Querol et al., 2002; Artiñano et al., 2003: Alastuey et al., 2004; Salvador et al., 2004; Shah et al., 2006; Viana et al., 2006; Yadav and Rajamani, 2006).

In recent decades, there has been a growing concern for the potential contribution of ingested dust to metal toxicity in humans (Chirenje et al., 2006; Inyang and Bae, 2006). Some trace metals (such as Cu and Zn) at small amounts are harmless, but some (notably Pb and Cd) even at extremely low concentrations are toxic and are potential cofactors, initiators or promoters in many diseases including cardiovascular diseases and cancer (Dockery and Pope, 1996; Willers et al. 2005). Young children are more likely to ingest significant quantities of dust than adults because of the behavior of mouthing non-food objects and repetitive hand/finger sucking. Secondly, children have a much higher absorption rate of heavy metals from digestion system and higher hemoglobin sensitivity to heavy metals than adults (Hammond, 1982). Because of their ubiquitous distribution, non-degradable persistence and deadly nature, heavy metal poisoning is one of the most widespread pediatric health problems regardless of gender, race, ethnic origin and socioeconomic status (Casey et al., 1994). Sedimented dust on roofs in schools and in buildings near playgrounds could be one of the major pathways of childhood exposure. Of particular interest are the sources and pathways of hazardous particles that enter and deposit in a classroom environment and thus expose the occupants, particularly children, in the dwelling to levels of contaminants above safe limits. Components and quantity of dust deposited in roofs at schools could provide an indirect measurement of air pollution integrated over varying time periods. However, there is a lack of information on sedimented dust and consequently, most developing countries do not have regulations, guidelines, or standard tests for heavy metal contamination in schools.

The city of Hermosillo, in northwestern Mexico was chosen for this study. This city is a rapidly developing area in a desertic environment where long periods of no precipitation are common and atmospheric dry deposition occurs. Hermosillo contains a poor soil cover that allows re-suspension of soil particles and 20% of the city's surface remains un-surfaced. A recent study (Cruz, 2005) characterizes the air quality in Hermosillo as bad or not satisfactory for the studied period (June 2001–May 2002), indicating that the TSP commonly exceeds maximum levels of 260 $\mu g\,m^{-3}$ for 24 h. Yearly maximum allowable limit of 75 $\mu g\,m^{-3}$ of TSP (According to Mexican official standards: NOM-025-SSAI-1993) was also out of compliance for the northcentral area of the city (Fig. 1). While this city contains a large industrial and agricultural activity in northwestern Mexico, no work, to our knowledge, has been undertaken to investigate the heavy metal accumulation in this area. Therefore,

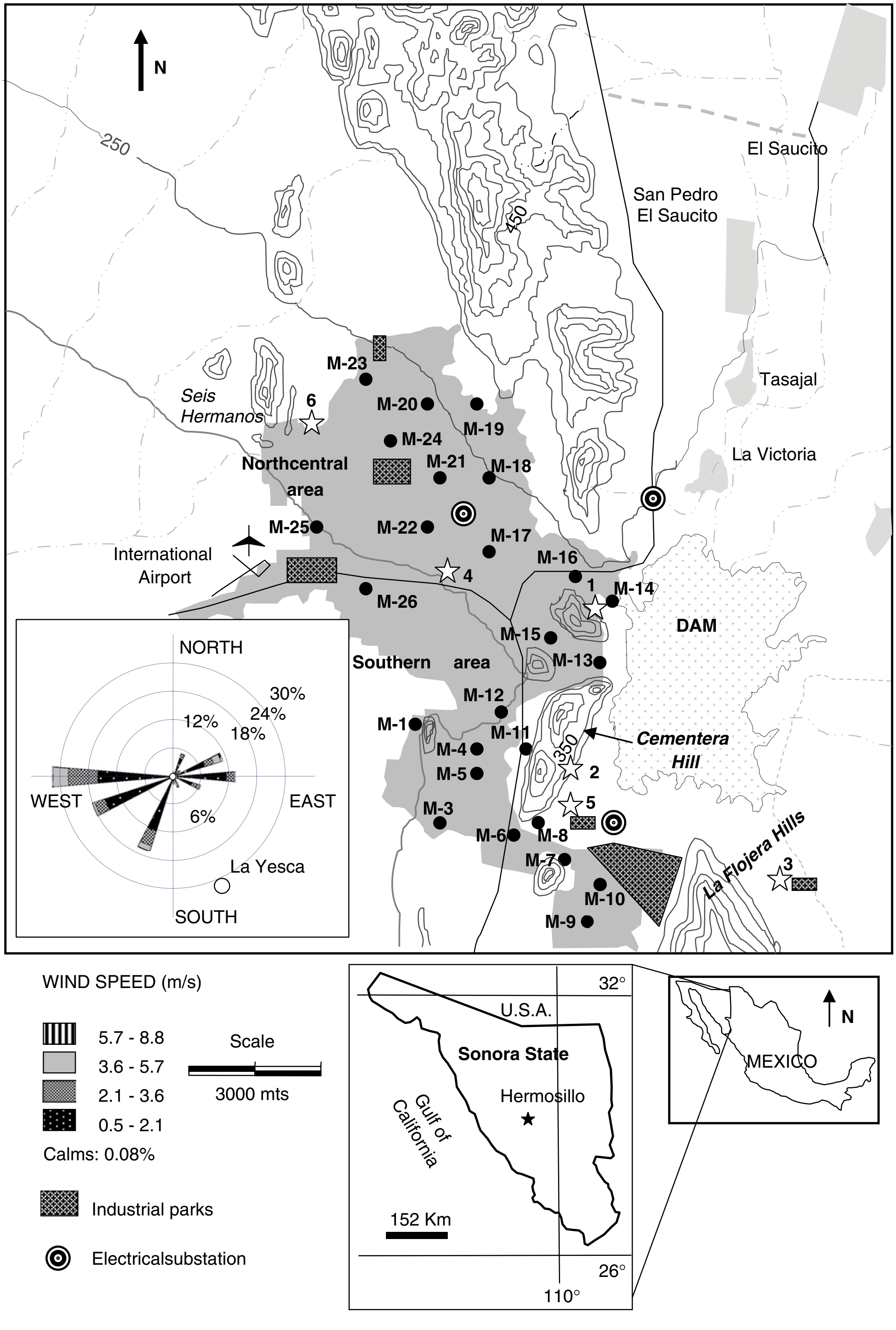

Fig. 1. Study area map showing prominent physiographic features, wind directions and sampling sites. Stars indicate the following sites: (1) Petrochemical industry; (2) and (3) cement industries; (4) car painting industry; (5) car assembly industry; (6) clay mining industries.

the present work is an earnest effort as to provide a common picture on the current load of pollutants in the form of dust in a rapidly growing urban area.

The objectives of the present investigation were to carry out a general survey of distribution of heavy metals including Cd, Cr, Co, Cu, Ni, Pb, V and Zn in outdoor dust in Hermosillo and to evaluate the quality of dust with respect to their metal content.

2. Methodology

2.1. Study area

The city of Hermosillo, State of Sonora (29°-04′23″ N, 110°-57′33″W) is located in northwestern Mexico, at an altitude of 210 m above sea level (29°04′23″ north latitude, 110°57′33″ west longitude), being about 200 km from the southern border with the United States. It represents a semi-arid urban area surrounded by agricultural and industrial activities. It is a rapidly growing city, extending over with urban population of approximately a 740 000, compared with about 300 000 in 1980. The prevailing wind direction is gusting from southwesterly to north-easterly (Fig. 1, wind rose). The soil in the investigated area is dark-brown with a pH from 7 to 8. It is mainly composed of silt and residual calcareous bedrock. The texture analysis of the soil shows that it is sandy clay, composed of sand (52.2%), clay (31.42%) and silt (16.36%). The investigated area is dominated by granite and lime-stone. Large parts of the studied area are covered by soil and the semi-arid terrain favours the re-suspension of soil dust. The climate in Hermosillo is mostly warm and dry, with temperatures reaching 38–42 °C during summer, but it is often cold during winter with temperatures reaching as low as 7 °C. The city has 17 industrial parks. Fig. 1 shows the main industrial sites, the biggest park is located in the southern part of the city (Fig. 1). The northcentral area host clay mining activities (Fig. 1) which is one of major dust sources that could locally influence ambient total suspended particle levels (natural particles). The industries located in this area are mainly textile. The southern area has high vehicular traffic density and a larger number of industries are located within this sector. The industries located in this sector are: flour mills, ceramics, clothes, textile, construction, metal and minerals, agriculture and livestock, cement manufacturing plants, paints, automotive industry, electric and electronics. Three power substations are located across the city and one petrochemical complex is located in the northeast section of the city (Fig. 1).

Winds are the principal transport mechanism of dust particles liberated from anthropogenic or natural sources. The wind patterns experienced throughout the region are shown as wind roses in Fig. 1. These diagrams show that the prevailing wind directions are from the southwest to northeast. Local topographic factors also tend to give rise to local flows, especially at the southern area where the Cementera and La Flojera Hills crop out (Fig. 1). Such topographic features act like a natural barrier avoiding the dispersion of heavy metals to the northcentral area of the city.

2.2. Sample collection

Sampling sites were selected to cover various areas in Hermosillo, including industrial areas, heavy and low traffic density areas and commercial areas. Sedimented dust in roofs of 25 elementary schools was collected from within two square meters using polyethylene brush, tray and containers. The sampling data were chosen at the end of the dry summer season (during October 2005).

2.3. Analytical procedures

Collected dust samples were dried at 100 °C and pass through a 200-μm mesh screen (clay). This size was chosen because finer fractions generally contain higher metal concentrations (Duggan and Inskip, 1985; Gulson et al., 1994, 1995; Whicker et al., 1997) and particles below this size are considered hazardous, as they easily adhere to children's hands (Duggan and Inskip, 1985). Dried samples 2.00 g each were accurately weighed, digested with 10 ml of HNO_3 60% and left overnight. The digested samples were ultrasonicated for 1 h and heated for another hour at 65 °C. The final extracts were filtered into a 25 ml volumetric flask through 0.45 μm filters and then diluted to the mark with 1% HNO_3 solution.

Heavy metals were determined using a Perkin-Elmer ICP-OES model Optima 4200 DV inductively coupled plasma optical emission spectrometer. Detection limits for analyzed metals are: Ba (1 mg kg^{-1}), Cd (0.005 mg kg^{-1}), Cr (0.010 mg kg^{-1}), Cu (0.010 mg kg^{-1}), Ni (0.010 mg kg^{-1}), Pb (0.005 mg kg^{-1}), V (0.005 mg kg^{-1}), Zn (0.010 mg kg^{-1}), Fe (0.010 mg kg^{-1}). Calibration curves were obtained using 6 points with certified standards (High Purity

Standards). Blanks were determined by completion of the full analytical procedure without samples. After each analytical run, the calibration curve was displayed on the screen, and a visual check was made for linearity and replication. Chemicals were analytical grade (MERCK). Pyrex glassware was washed several times with soap, distilled water and diluted hydrochloric acid to remove any adhered impurities. An estimate of volatiles (Loss of Ignition) was obtained by heating the samples at 550 °C. Results are shown in Table 1.

3. Results and discussion

3.1. Heavy metals in dust

The mean concentrations of Ni, Cr, Zn, Cd, Co, Ba, V, Pb, Fe and Cu in the roof dusts ($n = 25$) are shown in Table 1. In general, the dust samples of this study mainly consisted of inorganic materials. The organic content (OC) of this study (Table 1) fell well within the ranges of other studies on roadside dust (Fergusson and Ryan, 1984; Hildemann et al., 1991; Xie et al., 1999). There is no information available on heavy metals background values for soils in Hermosillo. Therefore, the data were compared with available background values (mean) for heavy metal concentrations reported in soils of cities from other regions (Table 2).

The mean total concentrations of Pb, Cd and Zn in the samples, which are 36.15, 4.24 and 387.98 mg kg^{-1}, respectively, are higher than the upper limits of their typical soil concentrations, 20.00, 0.30 and 90.00 mg kg^{-1}, respectively (Grimshaw et al., 1989; Bowen, 1979). This likely reflects an anthropogenic source. Conventionally, Pb has

Table 1
Metal concentrations (mg kg^{-1}) and enrichment factors for 25 roof dusts from the Hermosillo city, México

Sample	Roof type	Ba	Cd	Cr	Co	Cu	Ni	Pb	V	Zn	Fe	LOI (%)
Southern area												
M-1	Corrugated iron	45.13	3.10	2.29	0.83	10.68	2.30	10.23	2.29	311.25	1088.80	7.92
M-3	Corrugated iron	60.75	2.35	8.76	2.63	13.00	4.40	32.63	5.49	106.50	1887.50	10.08
M-4	Corrugated iron	41.00	6.46	5.29	1.74	22.00	3.80	25.88	4.05	84.88	1950.00	10.37
M-5	Corrugated iron	43.90	3.19	4.75	1.74	20.25	4.33	18.88	5.43	98.00	1837.50	17.17
M-6	Corrugated iron	45.80	28.38	15.88	1.60	21.88	4.51	101.88	6.29	1425.00	1975.00	18.37
M-7	Polymer	48.90	1.94	4.75	1.95	10.94	5.04	10.90	4.86	47.62	2025.00	17.88
M-8	Polymer	59.10	3.44	13.25	2.51	21.00	6.10	66.63	8.86	331.25	2225.00	22.07
M-9	Polymer	59.10	2.25	5.75	2.09	11.81	4.18	16.50	4.90	2012.50	1812.50	12.12
M-10	Cement tile	59.30	3.28	14.38	2.06	22.63	5.25	19.38	6.91	111.00	2662.50	—
M-11	Polymer	54.00	3.76	6.01	2.50	25.00	4.48	91.75	7.46	101.88	3112.50	16.12
M-12	Cement tile	54.60	5.95	22.00	2.81	47.5	4.95	60.50	6.31	446.25	2600.00	21.14
M-13	Corrugated iron	58.30	3.79	14.50	2.28	32.75	4.56	60.50	6.91	357.50	2637.50	25.38
M-15	Corrugated iron	70.50	5.58	33.00	3.41	61.50	6.55	118.5	9.98	792.50	4625.00	38.72
Mean		53.88	5.65	11.59	2.17	24.69	4.65	44.13	6.13	478.93	2697.20	—
$EF_{crustal}$		1.66	805.68	17.90	1.67	7.63	0.90	48.12	0.58	98.64	—	—
Northcentral area												
M-14	Polymer	67.38	3.99	7.15	2.84	51.50	7.58	25.38	20.25	136.25	3800.00	48.69
M-16	Corrugated iron	48.50	2.30	5.66	1.70	18.50	3.85	19.38	6.21	86.00	2587.50	12.42
M-17	Cement tile	71.13	5.43	14.63	3.66	43.13	6.44	63.38	7.41	166.25	3037.50	23.51
M-18	Cement tile	60.00	3.66	9.01	3.00	29.13	4.78	33.25	8.26	118.38	2800.00	19.07
M-19	Cement tile	66.50	2.05	38.13	2.50	25.63	4.65	39.63	7.24	1350.00	3025.00	17.74
M-20	Cement tile	60.38	1.81	5.86	0.41	16.62	4.41	13.88	6.45	108.88	2837.50	12.74
M-21	Cement tile	62.30	3.00	7.19	2.46	22.75	4.65	20.63	6.71	104.63	3025.00	15.07
M-22	Cement tile	58.40	2.26	12.04	2.18	35.38	4.75	35.75	6.71	1047.50	2587.50	21.54
M-23	Corrugated iron	56.50	1.09	9.58	2.00	11.06	3.66	25.13	4.06	152.50	2075.00	12.76
M-24	Cement tile	72.88	3.54	8.40	2.56	27.88	4.96	24.00	7.73	112.88	3175.00	10.40
M-25	Corrugated iron	42.50	1.78	4.48	1.76	18.00	3.34	15.00	4.38	70.50	1850.00	17.04
M-26	Corrugated iron	45.13	3.06	6.30	1.85	36.13	3.90	22.63	5.96	110.63	2075.00	24.39
Mean		59.30	2.83	10.70	2.24	27.98	4.75	28.17	7.61	297.03	2739.60	—
$EF_{crustal}$		1.80	397.31	16.27	1.70	8.51	0.91	30.24	0.71	60.23	—	—

LOI: Loss of ignition.

Table 2
Elemental concentrations and enrichment factor (EF) in sedimented dust collected in this study and a comparison with heavy metals in soil-forming rocks, urban and street dusts found in studies globally ($\mu g\,g^{-1}$).

Hermosillo ($mg\,kg^{-1}$) ($n = 25$)			Montana, USA	Hong Kong	London, England	Palermo, Italy	Kayseri, Turkey
Element	Mean	EF	Mean ($mg\,kg^{-1}$)				
Ba	56.59	1.73	707.00			250.00	
Cd	4.24	601.49	21.80	7.00	1.00	1.10	2.53
Cr	11.15	17.09	39.00	263.00		103.00	29.00
Co	2.21	1.69	10.00			7.00	16.50
Cu	26.34	8.07	2950.00	143.00	73.00	98.00	36.90
Ni	4.70	0.91	14.30			14.00	44.90
Pb	36.15	39.18	5532.00	263.00	294.00	544.00	74.80
V	6.87	0.65	76.60			13.00	
Zn	387.98	79.44	6952.00	1883.00	183.00	207.00	112.00

Abbreviations are: nr, not reported values; *, non-certified values; EF, enrichment factor.
Hong Kong: Leung et al. (2003); London: Thornton (1991); Palermo: Varrica et al. (2003); Kayseri: Tokalioglu and Kartal (2006); Montana : NIST-SRM 2710, Department of Commerce United States of America, National Institute of Standards and Technology (NIST).

been the most reliable indicator of traffic-induced pollution. Much work has been done on the generation, distribution, transportation and chemical composition of lead bearing exhaust particles (Lewis, 1985). The utilization of lead petrol as fuel for automobiles has not been used in Mexico since 1993. This practice was expected to have reduced greatly the accumulation of this element in the atmosphere. Table 3 shows a correlation of Pb and V of 0.584 for samples from the older southern area where most heavy traffic is concentrated. Although Pb-values are not considerably high they might represent the residual lead particles that had accumulated over the years prior to the cessation of lead petrol utilization. Dust incorporating lead and other heavy metals such as Cd and Zn accumulates essentially within 1 m from the roads, as a result of airborne redistribution by automobiles (Al-Chalabi and Hawker, 2000). Cd, Cu, Pb and Zn are good indicators of contamination in soils because they appear in gasoline, car components, oil lubricants, industrial and incinerator emissions (Adriano, 1986; Alloway, 1990). For the heavy metal composition, our data on the levels of Zn (northcentral mean = $297.00\,mg\,kg^{-1}$, southern mean-$478.93\,mg\,kg^{-1}$) and Cd (northcentral mean = $2.83\,mg\,kg^{-1}$, southern mean = $5.65\,mg\,kg^{-1}$) are higher than reported values in London, Palermo and Kayseri (Table 2). Samples M-6, M-9 (southern area),and M-19, M-22 (northcentral area) show the highest Zn-concentrations. Samples M-6 and M-9 are located near the biggest industrial park in the city and close to an electrical substation. Samples M-19 and M-22 also contain the highest Cr values in samples from northcentral area. Both samples are located near electrical substation and a car-painting business (Fig. 1, number 4). The high values could be related to these emission sources. Zn may also come from lubricating oils and tires of motor vehicles (Akhter and Madany, 1993) because

Table 3
Pearson's correlation matrix for the metal concentrations

	Ba	Cd	Cr	Co	Cu	Ni	Pb	V	Zn
Northern area									
Ba	1.000								
Cd	0.290	1.000							
Cr	0.158	0.002	1.000						
Co	0.290	0.573	0.089	1.000					
Cu	0.165	0.619	0.005	0.387	1.000				
Ni	0.516	0.572	0.013	0.372	0.705	1.000			
Pb	0.284	0.392	0.283	0.572	0.274	0.252	1.000		
V	0.195	0.234	0.001	0.132	0.541	0.737	0.006	1.000	
Zn	0.045	0.057	0.699	0.010	0.009	0.000	0.140	0.003	1.000
Southern area									
Ba	1.000								
Cd	0.082	1.000							
Cr	0.436	0.065	1.000						
Co	0.654	0.038	0.525	1.000					
Cu	0.263	0.009	0.819	0.510	1.000				
Ni	0.463	0.032	0.524	0.652	0.348	1.000			
Pb	0.172	0.260	0.520	0.336	0.484	0.295	1.000		
V	0.525	0.005	0.574	0.661	0.458	0.821	0.584	1.000	
Zn	0.040	0.197	0.041	0.000	0.001	0.000	0.054	0.002	1.000

all mentioned samples are located near the main road of the city. Fig. 2 shows plots of Cd, Zn, Pb and Cr and reference lines for street dust (Tokalioglu and Kartal, 2006) and uncontaminated soil (Lindsay, 1979; Al-Chalabi and Hawker, 2000) for comparison.

Pearson's correlation coefficients of heavy metals in studied samples are summarized in Table 3. High correlation of Fe and Cu ($R^2 = 0.76$) proves that vehicular and industrial activities are the main source of heavy metals in the southeastern area of the city. Fe–Cu correlation coefficient is low ($R^2 = 0.33$) for the samples from the north-central area of the city (Table 3). V can be held as the most important element for tracing the emissions of a power station (Boix et al., 2001; Querol et al., 1996). Along with Ni, V has been traditionally considered as a characteristic element of fuel combustion processes (Boix et al., 2001; Querol et al., 1996). Ni and V are highly correlated in northcentral and southern areas of the city (Fig. 3, Table 3). Samples M-14, M-15 show the highest concentrations of Ni

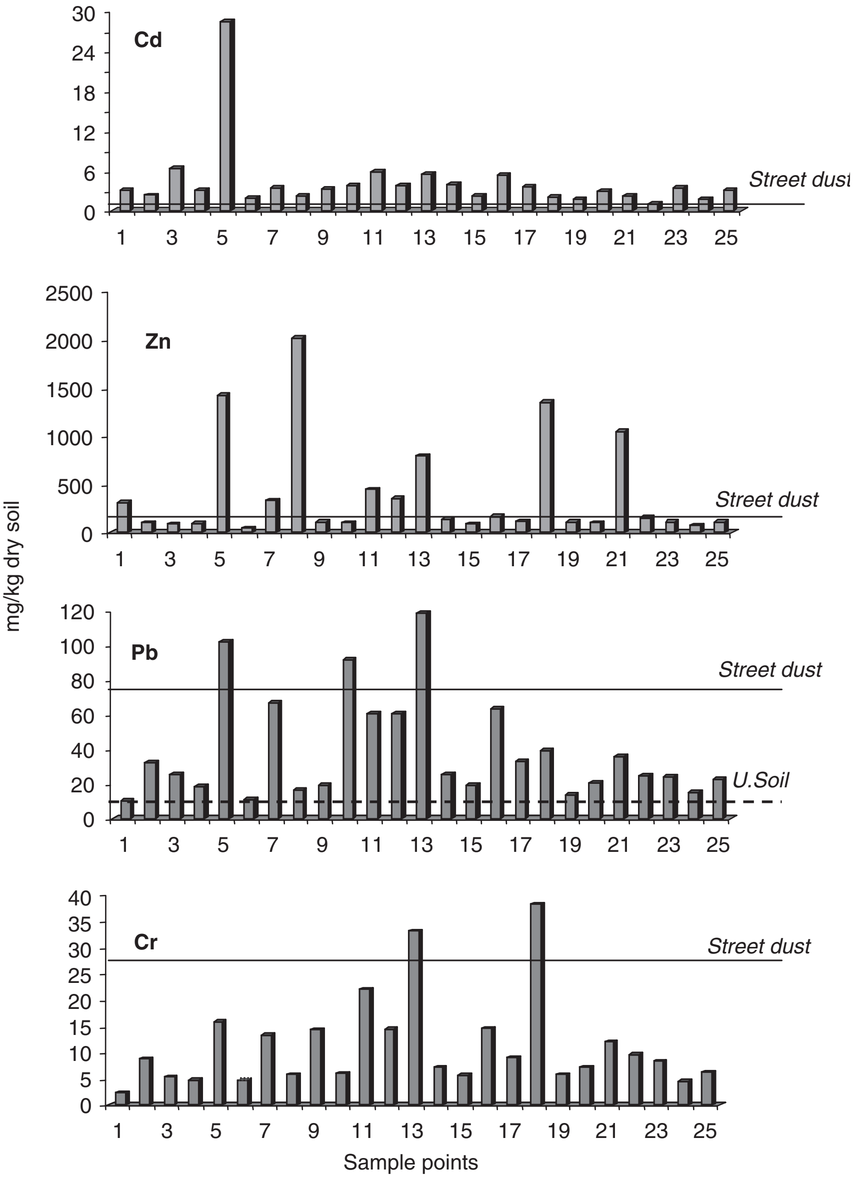

Fig. 2. Plots showing heavy metal concentrations in dust sample. Reference lines are: U.Soil- uncontaminated soil (Lindsay, 1979; Al-Chalabi and Hawker, 2000). Street dust (Tokalioglu and Kartal, 2006).

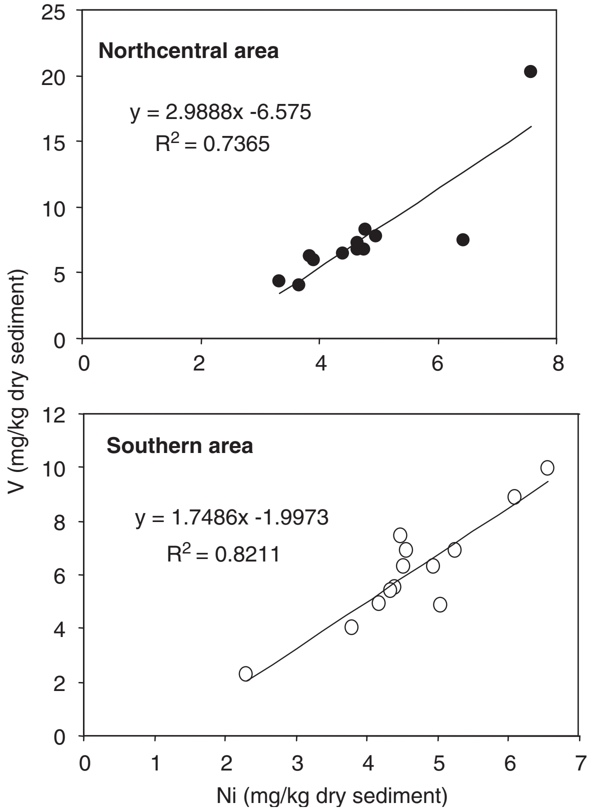

Fig. 3. Plots showing Ni vs. V concentrations in samples from the southern and northcentral areas of the Hermosillo city.

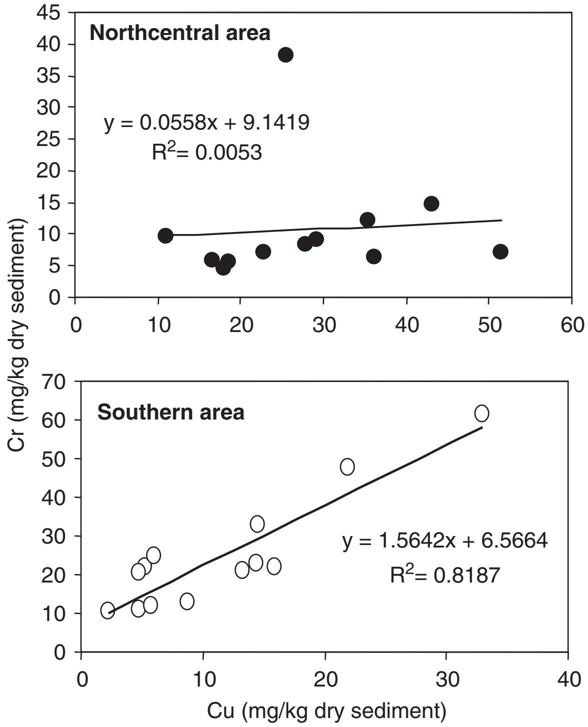

Fig. 4. Plots showing Cu vs. Cr concentrations in samples from the southern and northcentral areas of the Hermosillo city.

and V; these samples are located near a petrochemical industry and an electrical substation (Fig. 1) which could be potential sources of pollution. Cr–Cu are highly correlated in the southern area and poorly correlated in the northcentral area of the city (Fig. 4, Table 3). According to Jiries et al. (2001) Zn and Cu may be derived from mechanical abrasion of vehicles, as they are used in the production of brass alloy itself and come from brake linings, oil leak sumps and cylinder head gaskets.

3.2. Enrichment factors

Because of the limited number of studies involving roof dusts, there are no guidelines for levels of contamination, especially not for the majority of elements analyzed in this study. It is not possible to compare our results with those expressed as loadings in floor dust, for example, of $40\,\mu g\,ft^{-2}$ (USEPA, 2006). For this reason, enrichment factor have been calculated.

Enrichment factors (EF) can be used to differentiate between the metals originating from human activities and those from natural provenance, and to assess the degree of anthropogenic influence. The enrichment factor of an element X (EFx) in the sampled material with respect to its natural abundance in the earth's crust is calculated according to the following algorithm: $\mathrm{Efx} = (\mathrm{CnX}/E_{\mathrm{ref}})_{\mathrm{sample}}/(X/E_{\mathrm{ref}})_{\mathrm{crust}}$, where X is the concentration of the element of interest and E_{ref} the reference element for normalization. The elemental concentrations in the crust used in this study were the average continental crust data (Bowen, 1979; Taylor and McLennan, 1985). Fe was used as reference element assuming that its anthropogenic sources to the atmosphere are negligible. If EF approaches unity, crustal is the predominant source. On the other hand, EFs much higher than 10 are considered to originate mainly from anthropogenic sources (Liu et al., 2003). It seems, therefore, that EFs can also be an effective tool to differentiate a natural origin from anthropogenic sources in this study. The EFs obtained are presented in Table 2. The distribution pattern of EF values was found to be Cd > Zn > Pb > Cr > Cu > Ba > Co > Ni > V, which can also be seen as the decreasing order of their overall contamination degrees of studied dust.

Fig. 5 shows the enrichment factors in studied samples. The lowest EF values were found for V (0.65) and Ni (0.91) which would imply a slight contribution of anthropogenic sources. Moderate EF were found for Ba (1.73), Cu (8.07) and Co (1.69, whereas the most enriched heavy metals, for which significant anthropogenic origin can be suggested were Pb (39.18), Cd (601.49), Zn (79.44) and Cr (17.09). Fossil fuel combustion, traffic emissions, wear of brake lining materials, and several industrial processes are considered as major emission sources of these elements in the atmosphere (Watson et al., 2001; Samara et al, 2003).

3.3. Principal component analysis

Principal component analysis (PCA) is widely used to reduce data (Loska and Wiechula, 2003) and to extract a small number of latent factors (principal components, PCs) for analyzing relationships among the observed variables. If large differences exist in the standard deviations of variables, PCA results will vary considerably depending on whether the covariance or correlation matrix is used (Farnham et al., 2003). The concentrations of the heavy metals evaluated in this study vary by different orders of magnitude. PCA was therefore applied to assist in the identification of sources of pollutants. By extracting the eigenvalues and eigenvectors from the correlation matrix (Table 4), the number of significant factors, the percent of variance explained by each of them were calculated by using the software JMP4 and the results are given in Table 5.

From Fig. 6, samples are clearly split into two groups separated by a large distance in the PCA loading plot indicating that the two groups of samples are poorly correlated and have different

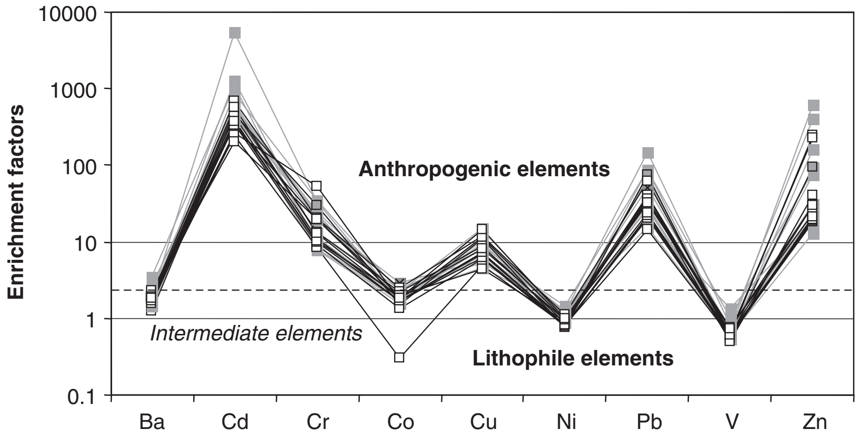

Fig. 5. Enrichment factors plotted against studied elements. Normalization values indicated in text.

Table 4
Correlation matrix for the metal concentrations

	Ni	Cr	Zn	Cd	Co	Ba	V	Pb	Fe	Cu
Ni	1.0000									
Cr	0.3990	1.0000								
Zn	0.0459	0.4491	1.0000							
Cd	0.0724	0.1797	0.3717	1.0000						
Co	0.6943	0.4840	0.0503	-0.042	1.0000					
Ba	0.6826	0.4814	0.1516	-0.195	0.6395	1.0000				
V	0.8280	0.2044	0.0097	0.0318	0.4818	0.5435	1.0000			
Pb	0.4209	0.5828	0.2881	0.5551	0.4857	0.2469	0.2338	1.0000		
Fe	0.7442	0.5302	0.0022	-0.055	0.6101	0.7413	0.7060	0.4714	1.0000	
Cu	0.6910	0.5275	0.0607	0.1082	0.6533	0.4690	0.6460	0.5386	0.7605	1.0000

Table 5
The results of principal component analysis ($n = 26$) and varimax rotated loadings for the sedimented dust samples ($n = 26$, only those larger than 0.1 are shown)

Component	Initial eigenvalues			Element	Principal components		
	Total	% of variance	Cumulative %		1	2	3
1	4.98	49.81	49.81	Ni	0.394		
2	1.87	18.68	68.49	Cr	0.299	0.301	0.426
3	0.98	9.82	78.31	Zn	0.088	0.499	0.471
4	0.73	7.32	85.63	Cd	0.055	0.586	
5	0.45	4.50	90.13	Co	0.359		0.083
6	0.37	3.74	93.87	Ba	0.344		0.390
7	0.23	2.32	96.19	V	0.337		
8	0.19	1.87	98.06	Pb	0.283	0.428	
9	0.11	1.13	99.19	Cu	0.379		
10	0.08	0.81	100.00				

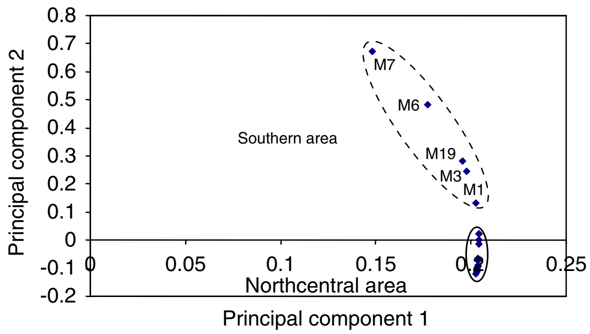

Fig. 6. Principal component graph showing two spatially separated groups of samples (southern and northcentral).

sources. One group is defined by samples from the southern area and the other is defined by samples from the northcentral area, this distribution could be related to the location of pollution sites, e.g. in southern area the occurrence of a significant industrial zone. The N–S oriented La Cementera and La Flojera Hills act like a natural barrier and avoid a wide spread of contaminants from the southern industrial zone into the northcentral area.

A 3-D plot of the PA loadings is presented in Fig. 7, and the relationships among the 10 heavy metals are readily seen. Just as expected, three factors were obtained, accounting for 78.31% of the total variance. Component 1 is dominated by Fe, Cu, V, Ba, Co and Ni, accounting for 49.81% of the total variance. In this case, the V loading (0.33729) is not as high as the loadings of the other elements of the group, which may, therefore, imply a quasi-independent behavior within the group. Component 2 is dominated by Cr, Zn, Cd and Pb, accounting for 18.68% of the total variance. Component 3 is

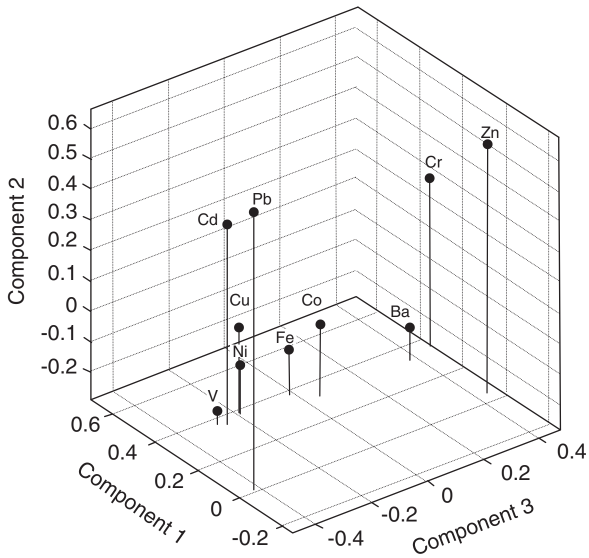

Fig. 7. PCA loading 3-D plot (PC1 vs. PC2 vs. PC3) for 10 metals.

dominated by Cr, Zn and Ba, accounting for 9.82% of the total variance.

3.4. Source identification

PCA has created an impression that Cd, Zn, Pb and Cr may have different sources from other elements. Compared with background values of continental crust (EFs) this group of elements has extremely elevated concentrations in sedimented dust which suggests anthropogenic sources for these elements. Fe, Ba, Co, Ni and V are correlated in PCA suggesting a common source. This group of elements is considered as intermediate according to

EFs, indicating a dominant natural origin with an anthropogenic influence (mixed sources). High correlation of Ni–V gives additional credence to the PCA and Efs analysis. PCA also distinguished samples collected in the southern area from those taken in the northcentral area of the city. In addition, sedimented dust samples collected in roofs from schools located at the southern area show significantly increased concentrations of heavy metals (e.g. samples M-6, M-8, M-13, Fig. 1, Table 1) compared to samples collected at the northcentral area.

3.5. Potential health implications

In arid and dusty zones, constant winds shift large volumes of dust that are deposited in roofs and ceilings causing it to be disturbed and redistributed into the indoor areas (classroom) exposing the occupants to metals and fine particles. The most sensitive subpopulation is young children, because of their extensive hand-to-mouth activity, whereby contaminated dust can be readily ingested. Cd in 14 studied samples was higher than the average values in soils and street dust from big industrial cities (Table 2). Cd is a cumulative toxic metal and the kidney is the main target for Cd toxicity (De Burbure et al., 2003). Secondary to kidney damage, the effect of Cd on the bone causing osteomalacia or osteoporosis has been well documented (Willers et al., 2005; Hossny et al., 2001). High values of Cd are restricted to the southern area showing a possible influence of the industrial zone where car assembly industries and cement manufacturing plant are located. In developed countries, most studies of heavy metal contamination in dusts are focused on Pb, Cu and Zn (Charlesworth et al., 2003). Little attention has been paid to other trace elements, such as Cd, therefore, its ecological and health implications need further detailed investigations.

4. Conclusions

The sources of the different elements in urban dust and soils are typically common to most urban environments (traffic, industry, natural substrate, etc.), but their intensities and patterns of distribution vary accordingly to the peculiarities of each city. In the case of Hermosillo city there are clearly some locations with significant heavy metal accumulations.

The following conclusions can be drawn:

- The chemical analyses of dust helped to estimate heavy metals levels in elementary schools. All determined elements but Cd are too low to yield any known health effect.
- The fact that TSP levels are higher in the northcentral area but the levels of metals are higher in the southern confirms the idea that the origin of TSP in the north is more related to natural sources than in the south. Mineral analysis should be conducted to prove this.
- The results of this study help to identify the distribution of heavy metals in two main sectors of the city (northcentral and southern areas). Such distribution seems to be conditioned mostly by location of pollution sites and transport of contaminants seem to be influenced by topographic features in the city (La Flojera and Cementera Hills) and wind direction. Such topographic features apparently prevent dispersion of contaminants to the northcentral area of the city. A decrease in heavy metal concentration is clear towards the northwest.
- Based on PCA and EFs the examined elements were classified into two main groups according to their sources: mainly natural with a slight to moderate anthropogenic influence (V–Ni–Cu–Fe–Co–Ba) and anthropogenic (Cd–Pb–Cr–Zn).
- Knowledge of metal concentrations in roof dusts may also be used as a guide to remediation or may indicate when roof dusts may be hazardous. Monitoring of the roofs and interiors of selected schools will possibly allow for evaluation of contributions of dust from the roofs and outdoor sources. Within the scope of this study, it is considered to carry out further studies on atmospheric transportation modeling.

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