Chemical composition of fugitive dust emitters in Mexico City

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Abstract

The gravimetric and chemical composition of fugitive dust emitters of Mexico City were analyzed to determine the particulate matter source profiles. Samples of geological material, unpaved and paved roads, agricultural soil, dried lake, asphalt, cement plants, landfill, gravel, and tezontle soil, were collected directly from the ground using a broom and a dustpan. These were dried, sieved and taken through a laboratory resuspension chamber to emulate the natural wind-blown processes of bulk soils and also to provide a uniform deposit on Teflon membrane and quartz fiber filters for further gravimetric and chemical analyses of $PM_{2.5}$ and PM_{10} size fractions. Chemical analyses of the filters included X-ray fluorescence for elemental composition, ion chromatography for water soluble anions, atomic absorption for water soluble metals, automated colorimetric analysis for ammonium and thermal/optical reflectance analysis for carbon species. The data show that most fugitive emitters are composed of 20–30% $PM_{2.5}$, which is relatively less than the reported contribution by fossil fuels and biomass (40–60%). © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: PM_{10}; $PM_{2.5}$; Source profile; Mexico City; Fugitive dust; Chemical mass balance

1. Introduction

In October of 1990, the Mexico City Metropolitan Area (MCMA) environmental authorities initiated the Integral Program Against Atmospheric Pollution (PIC-CA, 1990) in response to the Presidential Ordinance of December 1, 1988. This program recognized the importance of natural and anthropogenic particulate matter in the City's atmosphere. It recognized $PM_{2.5}$ as an important indicator of adverse health consequences to the lower respiratory tract where these fine particles are retained in the alveolar walls, producing possible allergies, asthma and lung emphysema (Air Resources Branch, 1995; Schprentz, 1996; Schwartz, 1996). Although most of the $PM_{2.5}$ in Mexico City's air originates from fuel combustion and secondary aerosol

formation, a substantial fraction is still contributed by fugitive dust from roads, construction, dry lakebeds, and disturbed surfaces. The MCMA emission inventory does not address $PM_{2.5}$, but for primary PM_{10} it estimates that fugitive dust contributes 54% of the total, with mobile source exhaust accounting for 28%, industrial emissions for 17%, and services accounting for 1%. (PICCA, 1990). PM_{10} standards are exceeded on many days throughout the year in Mexico City; there is currently no official standard for $PM_{2.5}$.

Several studies have reported mass concentrations (Cicero et al., 1993; Borja-Aburto et al., 1998; Edgerton et al., 1999) and chemical composition for atmospheric aerosols of MCMA (Miranda et al., 1994; Flores et al., 1998). There is little information on source emissions, however, especially the chemical composition in different size fractions. The most important use of these source profiles, the mass fraction of different chemical components in primary particle emissions, is for source apportionment using receptor models that quantify

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contributions from different source types to chemically-speciated ambient samples (Chow et al., 1993a; Chow and Watson, 1994a; Watson et al., 1990, 1991). The chemical mass balance (CMB) receptor model has been previously applied to particulate matter and non-methane hydrocarbons in Mexico City (Vega et al., 1997a, b) and will be used in the future to apportion PM_{10} and $PM_{2.5}$ using the profiles reported here. These profiles are also important for producing speciated emission inventories used for dispersion modeling and for health studies that attempt to determine the effects of toxic substances on respiratory and cardiac diseases.

This study reports for the first time chemical source profiles that represent several fugitive dust emitters in Mexico City. It also reports, for the first time, the fraction of each PM_{10} chemical abundance that is in the $PM_{2.5}$ fraction and shows that much of the potentially toxic species are in this fraction that may penetrate deep into the lung.

2. Methodology

Twenty-one geological samples were collected during 1997–1998 in and around Mexico City in the State of Hidalgo, and in Texcoco Lake (a dried basin to the East of MCMA), (Table 1). A portion of the surface dust was swept from representative portions of the surface and stored in a labeled polyethylene bag prior to analysis.

Samples were oven-dried at $< 50°C$ for more than 24 h to remove moisture while minimizing losses of volatile compounds such as nitrate and organic carbon. Samples from different locations for a given source type were thoroughly mixed and sieved for approximately 1–2 h through Tyler 30, 50, 100, 200, and 400 mesh sieves to obtain ~ 5 g of material (nominal geometric diameter < 38 μm for the 400 mesh sieve).

The sieved material was suspended in a chamber and sampled through size-selective inlets onto filters for analyses (Chow et al., 1994b). Approximately 100 μg of sieved material diameter was placed in a 250 ml side-arm vacuum flask sealed with a rubber stopper. Air puffs into the flask introduced dust into the chamber where it was sampled until 0.5–5 mg deposits were obtained on $PM_{2.5}$ and PM_{10} filters. Clean, filtered laboratory air was drawn into the chamber by the sample flow of 10 l/min through each filter. Filters for both $PM_{2.5}$ and PM_{10} were periodically weighed during the resuspension process to monitor loading. Teflon-membrane filters (#R2PJ047) of 47 mm in diameter (Gelman Scientific, Ann Arbor, MI) with 2 μm pore size collected samples for mass and subsequent elemental analysis. Quartz-fiber filters (#2500 QAT-UP) (Pallflex, Products Corp., Putnam, CT) collected samples on parallel channels for water-soluble anions (Cl^-, NO_3^-, SO_4^{2-}) and cations (Na^+, K^+, NH_4^+), organic carbon and elemental carbon analyses. The Teflon-membrane filters were equilibrated for 6 weeks in a relative humidity (25–35%) and

Table 1
Source type and sample description of Mexico City fugitive emitters sampled in 1997–1998[a]

Source type	Sampling area	Description
Paved road	La Merced, Xalostoc, Xochimilco	Road dust taken from Side Street N of Merced and Congreso de la Union Avenue, long edges between gutters and lane. Grey color with some white rocks.
		Road dust from Morelos Street near the Xalostoc PM_{10} site. Along edges between gutters and lane. Black in color.
		Dark paved road dust from Francisco Goytia Avenue.
Unpaved road	Xalostoc, Texcoco	Unpaved Road dust taken from Central Avenue, Xalostoc, Av. Acueducto and Cuauhtemoc in Xalostoc Sample taken along lines. Grey in color.
Agricultural soil	Milpa Alta, Texcoco	Agricultural soil taken from a potato field in Colinas del Mayorazgo. Brown in color. Harvested cornfield.
Dried Lake	Texcoco Lake	Dry lake bed sample, salty sample with grey and white color.
Landfill	Texcoco	The landfill was built onto the salty land of the Texcoco Lake, the sample was grey in color with some hardered pieces.
Asphalt	Pedregal	Coarse basaltic rocks from the asphalt plant. Iman Avenue. Fine basaltic dust mixed with asphalt. Iman Avenue.
Cement	Tula, Hidalgo	Pieces of hardered fugitive dust, pieces from under-storage in Cementera Tolteca. Large white flat pieces hardened by weather and ground for re-suspension.
Gravel	Tula, Hidalgo	Crushed gravel from vicinity of Cementera Tolteca. Very fine dust swept into dust-pan. Light red in color.
Tezontle soil	Texcoco	Tezontle road taken from a parking garage, red in color.

[a] Samples of the same source type were mixed to obtain a unique source profile.

temperature ($21.5 \pm 0.5^\circ$C) controlled environment before gravimetric analysis to minimize particle volatilization and aerosol liquid water bias. Filters were exposed to a low-level radioactive source (500 picocuries of polonium[210]) prior to and during sample weighing to remove static charge. Filters were weighed before and after sampling with a CAHN-33 microbalance. The balance sensitivity is ± 0.001 mg, although up to a ± 0.010 mg is allowed on periodic re-weights before all filters were submitted for re-weighing.

Chemical analyses of the filters included X-ray fluorescence for Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Br, Rb, Sr, Y, Zr, Mo, Pd, Ag, Cd, In, Sn, Sb, Ba, La, Au, Hg, T1, Pb, and U (Watson et al., 1999), ion chromatography (Chow and Watson, 1999) for water soluble Cl^-, NO_3^-, SO_4^{2-}, atomic absorption for water-soluble ($1Na^+$, K^+, automated colorimetry for water soluble NH_4^+, and IMPROVE thermal/optical reflectance for organic carbon (OC) and elemental carbon (EC) (Chow et al., 1993b, 1996, 2001).

3. Source profile results

Tables 2 and 3 present $PM_{2.5}$ and PM_{10} source profiles as mass fractions with their associated analytical uncertainties determined from blank subtraction and replicate analysis (Watson et al., 2001). Only 25 of the 40 measured elements were detected in at least one of the samples, and the tables report only these elements. Several values are reported that are close to or below their uncertainties, indicating that a detectable amount was present but not quantifiable. For example, the Cl^- abundance for the asphalt profile exceeds the total Cl abundance for the same profile, but the difference is within two precision intervals for the difference. As a result of the $PM_{2.5}$ asphalt Cl^- abundance being within two precision intervals of zero, it cannot be distinguished from zero for quantitative purposes. A similar situation is found for several of the K^+/K comparisons in Table 2.

Si, Fe and Ca are abundant in all samples, typical of most geological material. Asphalt, cement, gravel and tezontle have large OC abundances. The iron abundance is highest in the tezontle soil and the calcium abundances are highest in cement and gravel. All sources except for cement and gravel have significant Al (4–7%) abundances. Dried lake samples are enriched in K, Na, Mg and Cl. The content of Al, Si, Ti, Fe, Sr, and Zr are similar in both size fractions. The sulfate abundance in the $PM_{2.5}$ unpaved road profile is more than twice the abundance in the PM_{10} profile. K^+ and Na^+ abundances in PM_{10} are twice those of $PM_{2.5}$. Pb was most abundant in paved and unpaved road profiles, consistent with the continued use of leaded gasoline in Mexico City. The agricultural soil profile contained the highest Al abundance, and Fe was also abundant. Ca is most enriched, exceeding 30% of $PM_{2.5}$ and PM_{10}, for the cement and gravel profiles, thereby displacing Al, Fe, and Si to lower fractions. Landfill and asphalt profiles have high abundances of Al, S, Ti, Fe, Sr and Zr, while dry lake dust abundances for Na^+, K^+, K, Cl^-, Cl and Mg distinguish it from the other profiles.

Based on gravimetric analysis of the PM_{10} and $PM_{2.5}$ Teflon filters, $PM_{2.5}$ constituted 20–26% of the PM_{10} in paved road, agricultural soil, landfill, and asphalt. In unpaved road and tezontle soil, $PM_{2.5}$ represented 13% and 9% of PM_{10}, respectively. The $PM_{2.5}$ was highest for dried Lake Dust (31%) and cement (34%). The mass distribution is much more variable, however, for specific chemical components by particle size, as shown in Fig. 1. Soluble ions constitute a larger fraction of PM_{10} than most of the elements for most samples. The dry lakebeds $PM_{2.5}$ occupy especially high fractions of PM_{10}, especially for nickel and copper. Most of the selenium in cement is in the $PM_{2.5}$ fraction. These substances could be enriched because they coat the surface of soil particles, and the surface to mass ratio increases for smaller particle sizes. Larger fractions of potentially toxic metals than are indicated by the $PM_{2.5}/PM_{10}$ mass fraction area found in most of the profiles.

4. Conclusions

Chemical composition of the geological materials that produce fugitive dust emissions were determined for Mexico City. The $PM_{2.5}$ fraction constituted 23% of the PM_{10} total mass for most of the geological source profiles, except for unpaved road and tezontle soil where the percentage of $PM_{2.5}$ in PM_{10} was 11% and for the dried lake and cement where it was 32%. The $PM_{2.5}$ content of OC in the PM_{10} profile was variable, smaller for paved road, dried lake, landfill and cement and larger for unpaved road, agricultural soil, crushed gravel and tezontle soil. $PM_{2.5}$ and PM_{10} chemical abundances for a given source type were similar for most species. The high content of ions (Na^+, K^+) and the low abundance of OC characterized the dried lake profile, while the OC, nitrate and sulfate abundances differed among paved road, unpaved road and agricultural soil. Cement and crushed gravel profiles had the highest Ca abundances, while the Fe abundance in Tezontle soil was the highest of all the profiles.

Table 2
Average chemical composition (in mass percent) of fugitive dust samples in $PM_{2.5}$

[a]	Paved road	Unpaved road	Agricultural soil	Dry lake	Landfill	Asphalt	Cement	Gravel	Tezontle soil
Cl^-	0.06 ± 0.08	0.6 ± 0.1	0.13 ± 0.07	0.6 ± 0.1	0.07 ± 0.07	0.2 ± 0.1	0.02 ± 0.08	0.09 ± 0.06	0.1 ± 0.1
NO_3^-	0.00 ± 0.08	0.55 ± 0.08	0.14 ± 0.07	0.15 ± 0.10	0.00 ± 0.07	0.10 ± 0.10	0.13 ± 0.08	0.10 ± 0.06	0.3 ± 0.1
SO_4^{2-}	0.23 ± 0.09	8.6 ± 0.7	0.83 ± 0.10	0.7 ± 0.1	0.22 ± 0.08	0.7 ± 0.1	3.0 ± 0.3	0.29 ± 0.07	0.7 ± 0.1
NH_4^+	0.16 ± 0.09	0.21 ± 0.08	0.20 ± 0.08	0.12 ± 0.10	0.13 ± 0.07	0.2 ± 0.1	0.05 ± 0.07	0.00 ± 0.06	0.1 ± 0.1
Na^+	0.14 ± 0.07	1.8 ± 0.1	0.28 ± 0.06	3.0 ± 0.2	0.34 ± 0.06	0.67 ± 0.09	0.21 ± 0.06	0.03 ± 0.05	0.7 ± 0.1
K^+	0.11 ± 0.07	1.00 ± 0.09	0.36 ± 0.06	0.83 ± 0.10	0.30 ± 0.06	0.26 ± 0.08	[b]	0.07 ± 0.05	0.52 ± 0.09
OC	1.9 ± 2.1	23.2 ± 2.5	10.1 ± 2.0	0.0 ± 2.5	0.4 ± 1.9	4.3 ± 2.6	19.9 ± 2.4	14.4 ± 1.9	8.2 ± 2.9
EC	0.9 ± 0.6	0.8 ± 0.5	1.0 ± 0.5	0.0 ± 0.6	0.0 ± 0.5	5.7 ± 1.8	3.0 ± 1.0	0.00 ± 0.4	0.0 ± 0.7
Mg	0.93 ± 0.10	0.79 ± 0.09	0.1 ± 0.2	2.1 ± 0.2	0.89 ± 0.10	0.21 ± 0.08	0.15 ± 0.05	0.10 ± 0.05	1.7 ± 0.2
Al	5.3 ± 0.4	4.2 ± 0.3	6.9 ± 0.5	3.7 ± 0.3	6.8 ± 0.5	5.9 ± 0.4	0.48 ± 0.05	0.67 ± 0.06	4.4 ± 0.3
Si	17.3 ± 1.2	14.6 ± 1.0	15.0 ± 1.1	15.6 ± 1.1	19.0 ± 1.4	14.7 ± 1.1	3.8 ± 0.3	2.8 ± 0.2	17.1 ± 1.2
P	0.12 ± 0.01	0.09 ± 0.01	0.26 ± 0.02	0.00 ± 0.04	0.05 ± 0.01	0.11 ± 0.02	0.00 ± 0.03	0.01 ± 0.02	0.05 ± 0.01
S	0.49 ± 0.04	1.05 ± 0.08	0.17 ± 0.02	0.54 ± 0.04	0.16 ± 0.02	0.23 ± 0.02	0.55 ± 0.04	0.06 ± 0.01	0.11 ± 0.02
Cl	0.16 ± 0.02	0.51 ± 0.04	0.10 ± 0.02	1.5 ± 0.1	0.10 ± 0.02	0.04 ± 0.05	0.0 ± 0.2	0.0 ± 0.2	0.05 ± 0.02
K	1.01 ± 0.08	0.98 ± 0.07	0.40 ± 0.03	2.3 ± 0.2	0.83 ± 0.06	0.72 ± 0.06	0.25 ± 0.08	0.25 ± 0.07	0.99 ± 0.08
Ca	5.1 ± 0.4	7.8 ± 0.6	1.30 ± 0.10	5.7 ± 0.4	2.6 ± 0.2	6.0 ± 0.4	31.2 ± 2.3	30.4 ± 2.2	6.2 ± 0.5
Ti	0.32 ± 0.06	0.22 ± 0.06	0.57 ± 0.07	0.19 ± 0.08	0.52 ± 0.07	0.44 ± 0.08	0.00 ± 0.08	0.01 ± 0.07	0.44 ± 0.09
Cr	0.01 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.01 ± 0.02	0.01 ± 0.01	0.00 ± 0.02	0.00 ± 0.01	0.00 ± 0.01	0.012 ± 0.008
Mn	0.068 ± 0.007	0.055 ± 0.006	0.118 ± 0.010	0.041 ± 0.006	0.090 ± 0.008	0.057 ± 0.007	0.006 ± 0.004	0.018 ± 0.004	0.13 ± 0.01
Fe	4.0 ± 0.3	3.2 ± 0.2	4.9 ± 0.4	2.5 ± 0.2	4.9 ± 0.4	3.3 ± 0.2	0.35 ± 0.03	1.7 ± 0.1	5.9 ± 0.4
Co	0.00 ± 0.06	0.00 ± 0.05	0.00 ± 0.08	0.00 ± 0.04	0.00 ± 0.08	0.00 ± 0.05	0.003 ± 0.007	0.00 ± 0.03	0.00 ± 0.09
Ni	0.003 ± 0.002	0.001 ± 0.003	0.003 ± 0.004	0.008 ± 0.003	0.004 ± 0.002	0.001 ± 0.005	0.004 ± 0.002	0.004 ± 0.002	0.007 ± 0.003
Cu	0.015 ± 0.002	0.008 ± 0.002	0.008 ± 0.002	0.007 ± 0.003	0.005 ± 0.002	0.006 ± 0.003	0.001 ± 0.004	0.002 ± 0.002	0.010 ± 0.004
Zn	0.087 ± 0.007	0.072 ± 0.006	0.019 ± 0.003	0.010 ± 0.003	0.012 ± 0.003	0.000 ± 0.005	0.000 ± 0.004	0.001 ± 0.003	0.022 ± 0.004
As	0.000 ± 0.009	0.000 ± 0.008	0.002 ± 0.006	0.001 ± 0.009	0.000 ± 0.006	0.000 ± 0.009	0.006 ± 0.005	0.043 ± 0.005	0.006 ± 0.009
Se	0.000 ± 0.003	0.000 ± 0.003	0.001 ± 0.003	0.002 ± 0.005	0.001 ± 0.003	0.001 ± 0.005	0.001 ± 0.004	0.000 ± 0.003	0.000 ± 0.005
Br	0.002 ± 0.003	0.000 ± 0.004	0.004 ± 0.002	0.028 ± 0.004	0.002 ± 0.002	0.002 ± 0.005	0.000 ± 0.003	0.000 ± 0.003	0.000 ± 0.005
Rb	0.005 ± 0.002	0.004 ± 0.002	0.003 ± 0.002	0.005 ± 0.003	0.007 ± 0.002	0.003 ± 0.004	0.002 ± 0.002	0.001 ± 0.003	0.006 ± 0.003
Sr	0.031 ± 0.003	0.035 ± 0.004	0.018 ± 0.003	0.040 ± 0.004	0.028 ± 0.003	0.035 ± 0.004	0.031 ± 1.003	0.022 ± 0.003	0.031 ± 0.004
Y	0.002 ± 0.004	0.001 ± 0.004	0.002 ± 0.004	0.001 ± 0.005	0.004 ± 0.003	0.001 ± 0.006	0.000 ± 0.004	0.000 ± 0.003	0.001 ± 0.006
Zr	0.017 ± 0.004	0.014 ± 0.004	0.026 ± 0.004	0.014 ± 0.005	0.025 ± 0.004	0.019 ± 0.005	0.003 ± 0.005	0.003 ± 0.004	0.017 ± 0.005
Ba	0.1 ± 0.2	0.2 ± 0.1	0.1 ± 0.1	0.2 ± 0.3	0.1 ± 0.2	0.2 ± 0.2	0.1 ± 0.2	0.1 ± 0.2	0.1 ± 0.3
Pb	0.038 ± 0.007	0.029 ± 0.007	0.005 ± 0.009	0.00 ± 0.01	0.004 ± 0.009	0.00 ± 0.01	0.000 ± 0.010	0.004 ± 0.008	0.01 ± 0.01

[a] Species above minimum detection limits are included in the source profile.
[b] Not valid.

Table 3
Average chemical composition (in mass percent) of fugitive dust samples in PM_{10}

[a]	Paved road	Unpaved road	Agricultural soil	Dry lake	Landfill	Asphalt	Cement	Gravel	Tezontle soil
Cl^-	0.51 ± 0.05	0.58 ± 0.05	0.10 ± 0.06	1.7 ± 0.2	0.18 ± 0.04	0.05 ± 0.05	0.013 ± 0.047	0.02 ± 0.02	0.09 ± 0.04
NO_3^-	0.07 ± 0.04	0.19 ± 0.03	0.08 ± 0.05	0.24 ± 0.06	0.06 ± 0.04	0.03 ± 0.05	0.08 ± 0.05	0.03 ± 0.01	0.10 ± 0.04
SO_4^{2-}	0.67 ± 0.06	3.5 ± 0.03	0.46 ± 0.06	1.6 ± 0.1	0.35 ± 0.04	0.22 ± 0.05	3.7 ± 0.3	0.13 ± 0 02	0.45 ± 0.05
NH_4^+	0.08 ± 0.04	0.05 ± 0.03	0.13 ± 0.05	0.06 ± 0.05	0.09 ± 0.04	0.03 ± 0.05	0.02 ± 0.05	0.00 ± 0.01	0.01 ± 0.04
Na^+	0.49 ± 0.04	0.63 ± 0.04	0.18 ± 0.03	7.2 ± 0.6	0.52 ± 0.04	0.16 ± 0.04	0.18 ± 0.04	0.01 ± 0.01	0.19 ± 0.02
K^-	0.23 ± 0.03	0.30 ± 0.02	0.20 ± 0.03	1.5 ± 0.4	0.36 ± 0.03	0.06 ± 0.04	0.16 ± 0.05	0.02 ± 0.02	0.14 ± 0.02
OC	13.9 ± 1.1	7.7 ± 0.7	5.6 ± 0.9	5.1 ± 1.3	3.1 ± 0.7	1.8 ± 1.1	23.2 ± 2.1	10.3 ± 0.6	4.6 ± 0.6
EC	1.3 ± 0.5	0.3 ± 0.2	0.6 ± 0.3	0.0 ± 0.4	0.0 ± 0.2	1.4 ± 0.8	2.6 ± 0.9	0 ± 0.059	0.0 ± 0.1
Mg	0.46 ± 0.05	0.47 ± 0.04	0.1 ± 0.1	1.4 ± 0.1	0.62 ± 0.06	0.28 ± 0.05	0.09 ± 0.04	0.12 ± 0.02	1.05 ± 0.08
Al	7.1 ± 1.8	7.3 ± 2.0	13.0 ± 3.4	4.8 ± 1.2	11.4 ± 3.0	11.0 ± 19	0.9 ± 0.2	1.2 ± 0.4	8.6 ± 2.5
Si	22.5 ± 6.0	23.1 ± 6.7	27.8 ± 7.7	19.2 ± 4.8	29.5 ± 8.2	26.4 ± 7.4	5.5 ± 1.4	4.5 ± 1.4	29.1 ± 8.7
P	0.10 ± 0.03	0.05 ± 0.02	0.3 ± 0.1	0.04 ± 0.03	0.06 ± 0.03	0.11 ± 0.04	0.00 ± 0.03	0.00 ± 0.02	0.07 ± 0.03
S	0.4 ± 0.1	1.2 ± 0.4	0.22 ± 0.06	0.5 ± 0.1	0.15 ± 0.04	0.14 ± 0.03	0.5 ± 0.01	0.06 ± 0.02	0.18 ± 0.06
Cl	0.5 ± 0.1	0.6 ± 0.2	0.12 ± 0.03	1.8 ± 0.4	0.15 ± 0.04	0.09 ± 0.04	0.0 ± 0.2	0.0 ± 0.2	0.004 ± 0.067
K	1.1 ± 0.2	1.2 ± 0.2	0.58 ± 0.10	2.4 ± 0.4	1.0 ± 0.2	1.0 ± 0.2	0.3 ± 0.1	0.3 ± 0.1	1.3 ± 0.3
Ca	5.2 ± 0.7	9.1 ± 1.4	2.0 ± 0.3	5.7 ± 0.8	3.0 ± 0.4	4.9 ± 0.7	31.7 ± 4.3	34.7 ± 5.5	10.0 ± 1.6
Ti	0.32 ± 0.03	0.28 ± 0.02	0.56 ± 0.04	0.24 ± 0.04	0.48 ± 0.03	0.59 ± 0.06	0.02 ± 0.04	0.038 ± 0.009	0.42 ± 0.03
Cr	0.007 ± 0.004	0.005 ± 0.006	0.00 ± 0.01	0.010 ± 0.008	0.007 ± 0.009	0.006 ± 0.009	0.001 ± 0.007	0.001 ± 0.003	0.008 ± 0.009
Mn	0.058 ± 0.004	0.055 ± 0.004	0.117 ± 0.008	0.038 ± 0.004	0.075 ± 0.005	0.066 ± 0.006	0.008 ± 0.002	0.014 ± 0.001	0.104 ± 0.007
Fe	3.5 ± 0.2	3.1 ± 0.2	4.9 ± 0.3	2.3 ± 0.2	4.5 ± 0.2	3.8 ± 0.3	0.53 ± 0.04	1.31 ± 0.07	5.6 ± 0.3
Co	0.00 ± 0.06	0 ± 0.05	0.00 ± 0.08	0.00 ± 0.04	0.00 ± 0.08	0.00 ± 0.06	0.002 ± 0.010	0 ± 0.021	0.00 ± 0.09
Ni	0.003 ± 0.001	0.002 ± 0.001	0.002 ± 0.003	0.004 ± 0.002	0.003 ± 0.001	0.002 ± 0.002	0.008 ± 0.002	0.013 ± 0.001	0.004 ± 0.001
Cu	0.014 ± 0.001	0.008 ± 0.001	0.007 ± 0.001	0.005 ± 0.002	0.006 ± 0.001	0.007 ± 0.002	0.002 ± 0.002	0.002 ± 0.000	0.005 ± 0.001
Zn	0.069 ± 0.004	0.064 ± 0.004	0.019 ± 0.002	0.013 ± 0.002	0.013 ± 0.001	0.006 ± 0.002	0.001 ± 0.002	0.002 ± 0.000	0.018 ± 0.001
As	0.000 ± 0.007	0.001 ± 0.005	0.001 ± 0.004	0.000 ± 0.005	0.000 ± 0.003	0.000 ± 0.004	0.006 ± 0.003	0.030 ± 0.002	0.004 ± 0.002
Se	0.000 ± 0.001	0.000 ± 0.001	0.001 ± 0.002	0.000 ± 0.002	0.000 ± 0.002	0.000 ± 0.002	0.001 ± 0.002	0.000 ± 0.001	0.000 ± 0.001
Br	0.001 ± 0.001	0.001 ± 0.001	0.003 ± 0.001	0.030 ± 0.003	0.002 ± 0.001	0.002 ± 0.002	0.000 ± 0.002	0.000 ± 0.001	0.000 ± 0.002
Rb	0.005 ± 0.001	0.005 ± 0.001	0.003 ± 0.001	0.005 ± 0.002	0.006 ± 0.001	0.003 ± 0.002	0.001 ± 0.001	0.001 ± 0.000	0.005 ± 0.001
Sr	0.031 ± 0.002	0.040 ± 0.002	0.025 ± 0.002	0.040 ± 0.004	0.033 ± 0.002	0.044 ± 0004	0.031 ± 0.003	0.021 ± 0.001	0.038 ± 0.002
Y	0.002 ± 0.001	0.003 ± 0.001	0.003 ± 0.002	0.001 ± 0.003	0.003 ± 0.001	0.003 ± 0.002	0.001 ± 0.002	0.001 ± 0.000	0.003 ± 0.001
Zr	0.016 ± 0.002	0.014 ± 0.001	0.027 ± 0.002	0.012 ± 0.003	0.024 ± 0.002	0.025 ± 0.003	0.003 ± 0.003	0.003 ± 0.001	0.018 ± 0.002
Ba	0.06 ± 0.06	0.07 ± 0.04	0.13 ± 0.06	0.0 ± 0.1	0.15 ± 0.06	0.10 ± 0.09	0.1 ± 0.1	0.00 ± 0.04	0.10 ± 0.05
Pb	0.035 ± 0.003	0.023 ± 0.002	0.005 ± 0.004	0.005 ± 0.006	0.005 ± 0.003	0.001 ± 0.006	0.000 ± 0.006	0.001 ± 0.002	0.006 ± 0.002

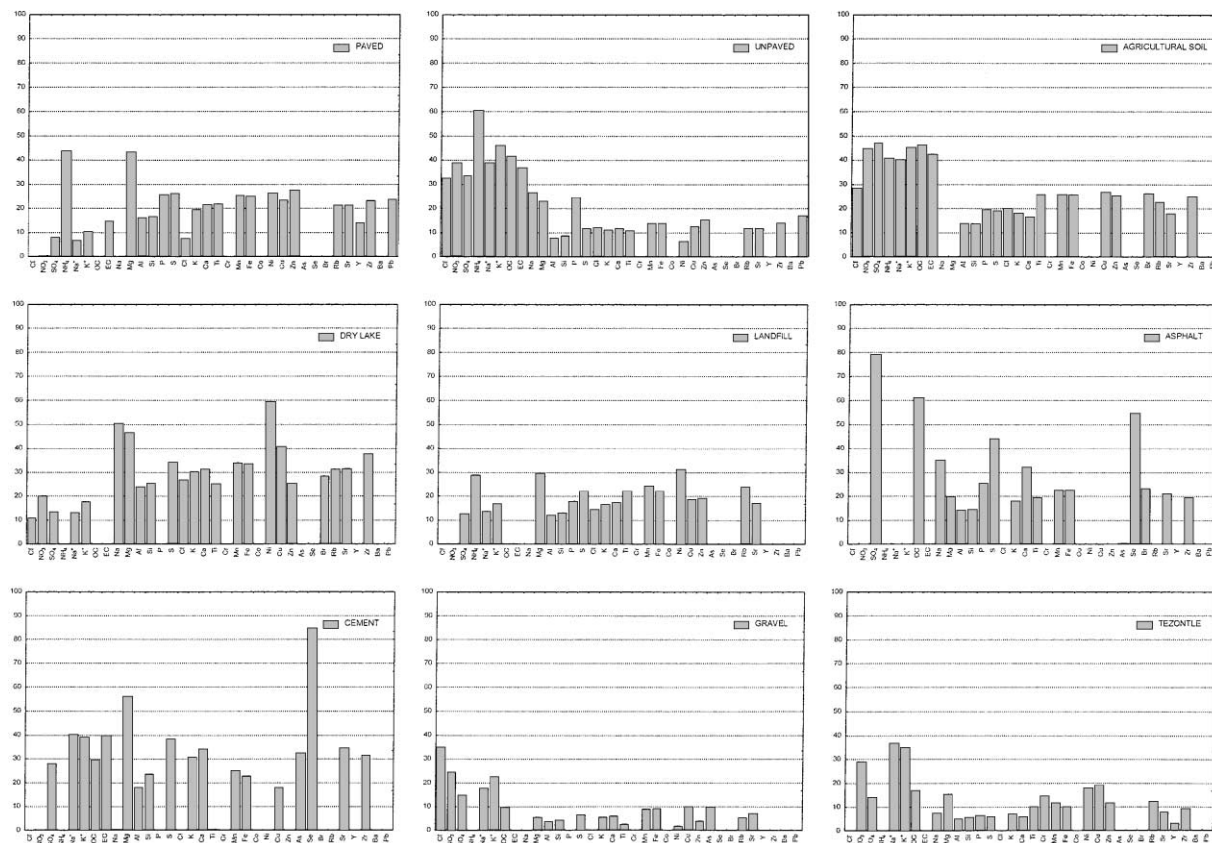[a] Species above minimum detection limits are included in the source profile.

Fig. 1. Fractional contribution of $PM_{2.5}$ chemical species in PM_{10} for different source profiles.

analyses of samples and the use of the resuspension chamber.

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