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Source Apportionment of Atmospheric Dust Fallout in an Urban-Industrial Environment in India

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ABSTRACT

The components and quantities of atmospheric dusts fallout has been reported to be the pollution indicator of large urban areas. The multiplicity and complexity of sources of atmospheric dusts in urban regions (e.g. industrial complexes composed of a variety of industrial processes, automobiles, construction activities etc.) has put forward the need of source apportionment of these sources indicating their contribution to specific environmental receptor. The study presented here is focused on investigation of source contribution estimates of dusts fallout in an urban-industrial area, Raipur, India. Six sampling sites have been identified on the basis of land use for development plan of anthropogenic activities and factors related to the transportation and dispersion pattern of atmospheric dusts. 12 samples of dusts fallout has been collected from each site (one in each month) and subjected to chemical analysis of selected chemical constituents known as markers of selected major dust emitting sources(Steel making average, Road traffic-borne dusts, construction activities, municipal waste burning, and soils). Chemical profiles alongwith SPECIATE of USEPA has been used for the preparation of source profiles. Source apportionment has been done using Chemical Mass Balance (CMB 8). Good fit parameters and relative source contribution has been analyzed and documented. Variations in source contribution estimates of selected indicator species has been occurred and justify the significant contribution of local area and line sources of dusts emission in various parts of the study region. Coal-fired steel making industries have shown dominating contribution compared to other sources.

***Keywords**:* Source apportionment; Dusts fallout; Chemical mass balance; Urban areas.

INTRODUCTION

Increasing severity of dispersion and fallout of fugitive dusts in urban areas of India has shown spontaneous linkage with higher degree of health disorders especially bronchial ailments (Quraishi and Pandey, 1995; Goel and Trivedi, 1998; Bohm and Saldiva, 2000; Sharma and Pervez, 2003; Sharma and Pervez, 2005; Saxena *et al.*, 2008). Due to higher settling tendency of bigger particles of dust near emission sources on a regional scale, researchers have made classification of its reception pattern as ambient-outdoor, street-outdoor and indoor dust fallout (Quraishi and Pandey, 1993; USEPA 2003; Sharma and Pervez, 2004; Gadkari and Pervez, 2007; Dubey and Pervez, 2008). Due to presence of a variety of point, line and area sources of dusts emission alongwith higher degree of variation in meteorological parameters, a non-uniform distribution of dusts in various environmental media has been reported earlier (Sharma and Pervez, 2004). Close deposition pattern and higher degree of relative contribution from local sources, especially temporary dust formation sources, compared to suspended fine particulates has been reported in earlier investigations (Sartor and Boyd, 1972; Pitt and Amy, 1973; Pitt, 1979; Mustard *et. al.*, 1985; Schroder and Hedley, 1986; Schroder *et. al.*, 1987; Illinois State Water Survey, 2003). Adachi and Tainosho (2004) have characterize the street dusts to investigate Zn as tire dust indicator in Japan using reference work done in the field of chemical apportionment of road-traffic settleable dusts earlier (Smolders and Rogge *et al.*, 1993; Davis *et al.*, 2001; Degryse, 2002). Atmospheric deposition of vanadium, lead, chromium, copper, zinc and nickel has been described earlier (Barceloux, 1999; Arslan, 2001; Dundar and Altundag, 2002; Dundar and Pala, 2003; Dundar and Turkoglu *et al.*, 2003; Tuzen, 2003; Deryaoglu, 2005; Dundar, 2006). Large size particles of dusts fallout in urban regions has been reported to be the major cause of prevalence of asthma (occur at upper nasal area) compared to association of fine particulates with inner respiratory disorders (Wieringa *et al.*, 1997; Sax and Richard, 1984; Roosli, 2000; USEPA, 2003).

Multiplicity and complexity of dusts emission and transportation has justified the need to determine relative contribution of coarse dusts from specific source (Begum *et al.*, 2007; Kothari *et al.*, 2008; Zhang *et al.*, 2008). It is possible to use statistical techniques to derive source category signatures, identify indoor-outdoor source category signatures, and estimation of their contribution to dusts of receptors (Yokovleva *et al.*, 1999; Andresen *et al.*, 2002; Chowdhury *et al.*, 2004). The effective variance weighed chemical mass can be used for source apportionment of air pollution studies (Watson *et al.*, 1997; 1998). A chemical mass balance model (CMB 8, EPA) consisting a set of solution of linear equations to express each receptor chemical concentration as a linear sum of products of source profile abundances and source contributions has been defined (Friedlander 1973; Cooper and Watson, 1980; Gordon, 1980; Watson, 1984; Watson *et al.*, 1984; Gordon, 1988; Hidy and Venkatraman, 1996).

The presented work has been focused on source apportionment of dust fallout in selected classified urban residential receptor of Raipur City, District Raipur, India which located in global scale of: 21°14’22.7” N latitude and 81°38’30.1” E longitudes. Regression analysis between various longitudinal measurements of selected and defined dust deposit regions has been utilized to identify possible sources/routes of dust transport to a receptor region. Chemical mass balance (CMB8, EPA) has been executed to investigate source contribution estimates of dust fallout in a

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specific ambient-outdoor receptor located in a residential area.

MATERIAL AND METHODS (STUDY DESIGN, SAMPLING AND DATA ANALYSIS)

Study Design

The study was undertaken in urban areas. The goal of the study is to evaluate relative source contribution estimates of various routes of dust fallout in urban residential environment. The objectives here are: (1) To measure and characterize dust fallout at identified sources (2) to analyze statistically, the relationship between dust fall measurements of source-routes and residential-receptors and (3) to carryout apportionment of dust fall at residential-receptors, taking identified atmospheric routes as possible sources using Chemical mass balance Model (CMB8). A residential area (Birgaon) located in close proximity to a major industrial area (Siltara) has been selected for the study. Apart from two major industrial sources of dusts emission, local soils, paved road dusts and automobile exhaust emissions alongwith construction activities have also been identified to cluster of source profiles for source apportionment. The details of location of residential colony (receptor), major industrial complexes, windrose and wind channels have been shown in Fig 1a and 1b.

Sampling Design

A comprehensive study about source contribution estimates of major possible and observable sources of dusts emission to dust fallout of urban areas (residential, commercial and sensitive regions) was started from yr 2007. Source apportionment study of dust fallout of a specific urban-residential region has been presented here. A non-probability based longitudinal stratified random sampling design in space-time frame work has been chosen to achieve the objectives (Gilbert 1987; USEPA, 2003). Ambient-outdoor and local-outdoor has been decided as atmospheric measurement levels at identified sources of dust emissions and residential-receptor, respectively (Table 1).

Sampling Method of Dust Fallout

Dust emission sources were identified using layout map, anthropogenic activity patterns and urban-industrial development plan of the study area. The identified sources (Table 1) were classified in point, line and regional sources of dust emission (Goel and Trivedi, 1998). Dust collection Jars (Dimension: dia- 23" ht- 45") with standard specifications(Katz, 1977; Thakur and Deb, 1999) has been placed for a month at a height of 10 ft (ambient-outdoor) and 5 ft(local-outdoor) at each source and receptor sites, respectively. In case of sampling at paved road, sampler was installed at the height of 5 ft at major cross road passing through the residential colony. As far as soil profile is concern, samples of soils (1 kg) have been collected from open land of residential colony. Soil samples were collected after removing surface soils upto 6 cm depth (Gadkari and Pervez,

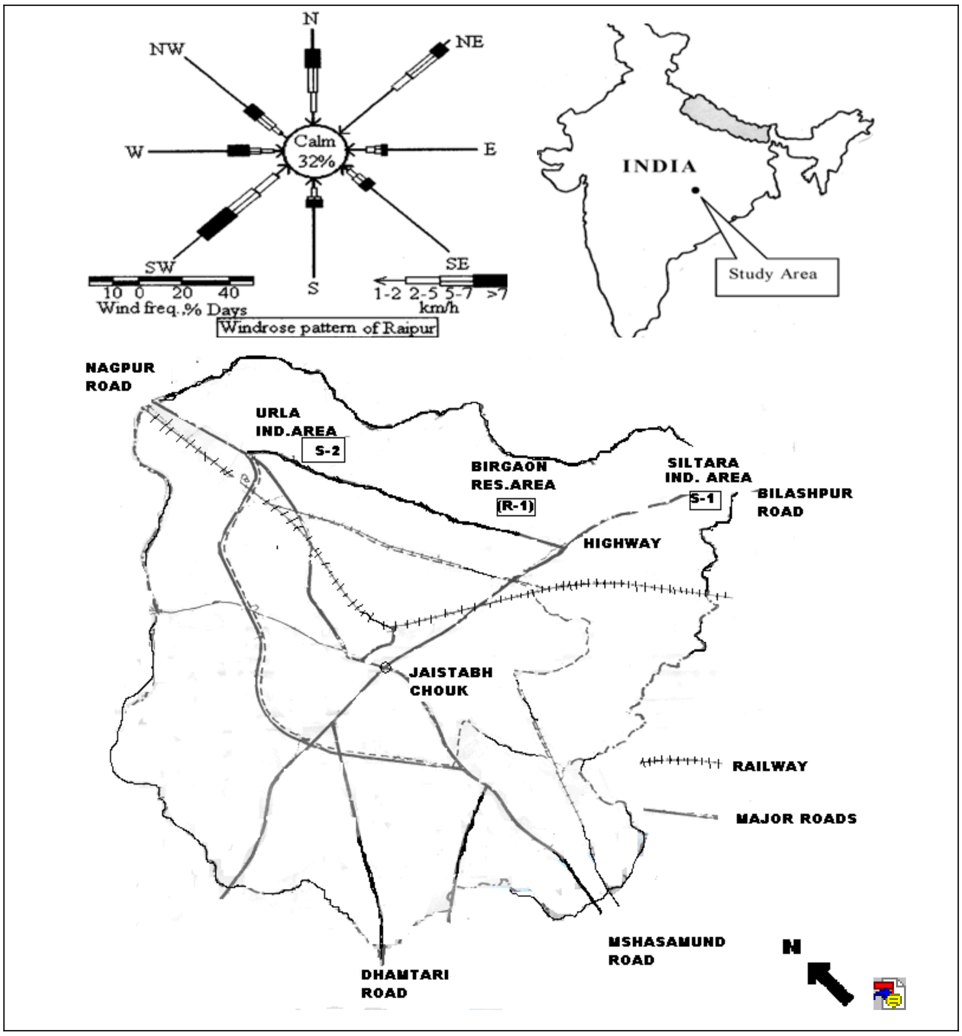

Fig. 1a. Local map of source and receptor sites in Raipur City along with annual windrose of the region.

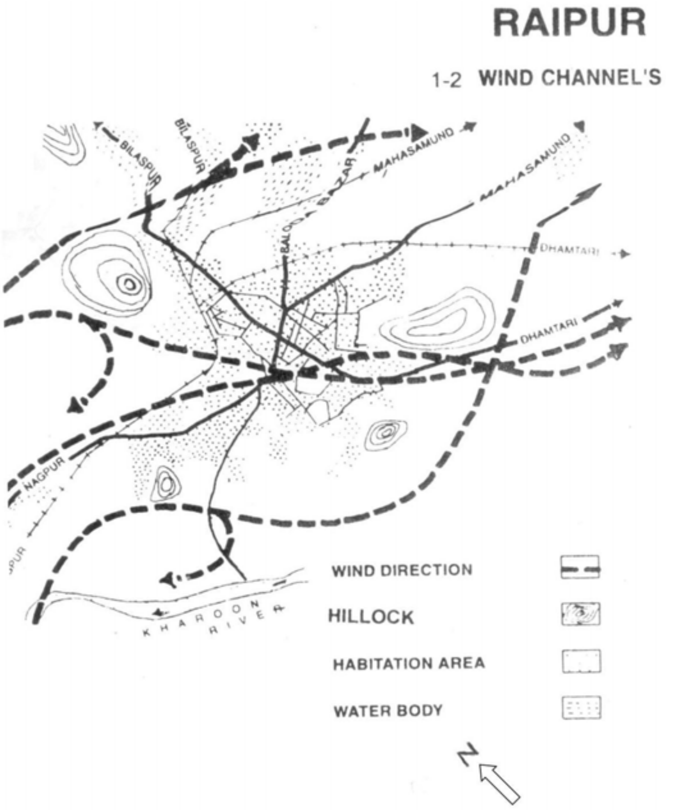

Fig. 1b. Wind channels over the Raipur Region, India during sampling year.

Table 1. Identification and grouping of defined sources and receptor in the study area.

S.No.	Name of Source/receptor	Type	Classification of monitoring level	Site characteristics	Sampling Frequency
			Source sites		
S-1	Siltara industrial area	Stationary point	Ambient-outdoor	Most of the industries are: casting, sponge iron, steel foundries.	
S-2	Urla Industrial, area	Stationary point	Ambient-outdoor	Most of the industries are: casting, chemical, oil production, glass and plastics.	
S-3	Paved road	Line	outdoor	Re-suspended dusts of road side runoff measured at 3 ft height	**12** samples throughout the sampling year(One in each month)
S-4	Automobile	Point	Emission outlet	Mixed dust fraction emitted from silencer of truck, cars and two wheelers	
S-5	Civil construction	Area	Ambient-outdoor	Dusts emitted from handling of raw materials used in civil construction site	
S-6	Local soils	Area source	-	Re-suspension of soil dusts	
			Receptor site		
R-1	Birgaon, Raipur	Residential area	Ambient-outdoor	Residential area located northeasterly and downwind to industrial complexes	**12** samples throughout the sampling year(One in each month)

2008). Frequency of sampling was twelve (one in each month) at each source-receptor site throughout the sampling year. About a liter of double distilled water was placed in each Jar and a net sheet (size: 20 mesh) was placed on mouth of the Jars. Water soluble and insoluble fraction of dust fallout has been measured separately and by adding them, total dust fallout was measured. Five replicate measurements were done to minimize weighing error (Table 2).

CHEMICAL ANALYSIS OF DUST FALLOUT

Digested samples of insoluble and soluble fractions of dust fallout were analyzed for (Fe, Al, Ca, Mg, Cr, Mn, Ni, As, Hg, V, Zn, Cu, Pb, Co and Sb) using ICP-AES (Jobin Ywuan, version 3.0) by standard procedures (Montaser and Golightiy, 1987). Sodium and Potassium were determined by flame photometer. Residue of digested samples has been used for the determination

Table 2. Dust fallout at selected source/receptor sites in Raipur, India during 2007-08.

SITE NO / PARAMETER	S-1* (SIND)	S-2(UIND)	S-3(ROAD)	S-4(CONST)	R-1
Dust fallout *(mt/km/m)*	192.85 ± 92.55 (104.15-391)	226.36 ± 22.86 (188.35-245.26)	154.78 ± 19.21 (124.29-186.25)	93.54 ± 17.55 (62.53-116.54)	80.16 ± 41.27 (147.36-41.3)

for silica (Katz, 1977; Bassett *et al.*, 1989). It was reported that organic carbon is vaporized at 500°C while elemental carbon is vaporized at 900°C (CPCB, 2007; 2007a). A portion of insoluble fraction of dust fallout was placed in a pre-weighed platinum crucible and heated at 500°C for 6 hrs in a muffle furnace (Labtech Model), after cooling, crucible was weighed and the process was repeated till constant weight was obtained. The difference in weight of pre- and post heating has been taken as organic carbon fraction of dust fallout. Again same sample was heated at 900°C till it became constant. The weight difference has been taken as elemental carbon fraction (CPCB, 2007; 2007a**)**. Selected source indicator anions (SO_4^{--}, Cl^- and NO_3^-) were also determined **(**Babko and Pilipenko, 1976; NEERI, 1988; Bassett, 1989; Christian, 2003**)**. Five replicate determinations (Three in case of OC/EC analysis due to availability of small fraction of dust) have been made in case of all species. Repeatability of determination has been increased where relative standard deviation has not been within 5-8%.

DATA ANALYSIS

Measurement data of dust fallout has been documented as geometrical mean and standard deviation of twelve measurements at each monitoring site and presented in Table 2. Regression analysis between annual mean of dust fallout measured at defined receptor site (local-outdoor of Birgaon residential region) and selected source sites (Siltara Industrial complex, Urla Industrial complex, paved road and construction sites) has been conducted and presented in Fig. 2.

The source profile abundances (mass fraction of chemicals in the emissions from each source type) and the receptor concentrations, with appropriate uncertainty estimates, serve as input data to the CMB model. The output consists of the amount contributed by each source type represented by a profile to the total mass and each chemical species. The CMB calculates values for the contributions from each source and the uncertainties of those values. The CMB is applicable to multi-species data sets. The CMB modeling procedure requires: (1) Identification of thecontributing source type; (2) selection of chemical species or other properties to be included in the calculation; (3) estimation of the fraction of each of the chemical species which is contained in each source type (source profile); (4) estimation of the uncertainty in both receptor concentrations and source profiles; and (5) solution of the chemical mass balance equations. The CMB is implicit in all factor analysis and multiple linear regression models that intend to quantitatively estimate source contributions (Watson, 1984). The chemical mass balance consists of a least squares solution to a set of linear equations which expresses each receptor concentration of a chemical species as a linear sum of products of source profile species and source contribution. Exact knowledge of dispersion factor of emissions is not necessary in receptor models (Watson, 1984). Geometric mean and standard deviation values of chemical parameters have been utilized for the concentration and

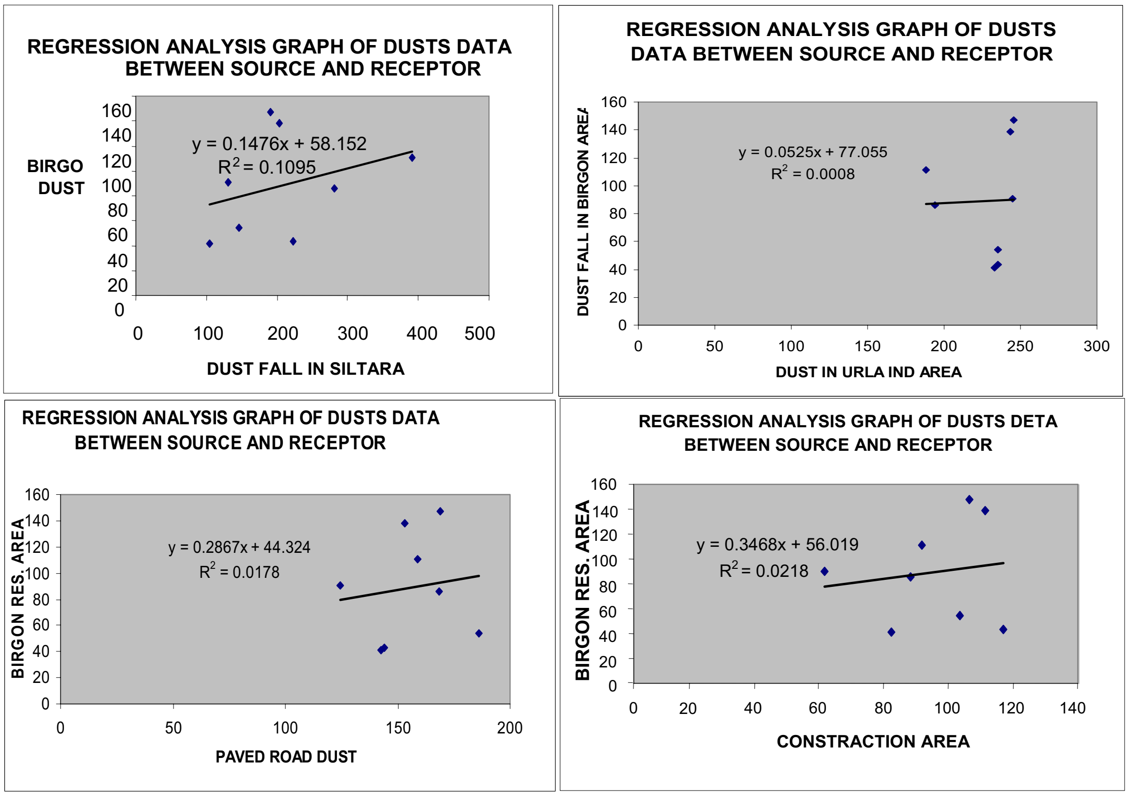

Fig. 2. Regression analysis of selected source dust fallout measurements with its component measured at receptor site.

uncertainties of corresponding species of specific site for development of source/receptor profiles. All prepared source and receptor profiles has been introduced in CMB model using an INFRA control file to execute source apportionment program (Watson *et al.*, 1997; 1998). Results of CMB execution have been presented in Figs. 3-4.

RESULTS AND DISCUSSION

Profuse and highly skewed dust fallout at outdoor receptor of Birgaon residential area has been observed. It has been observed that geometrical mean level of dust fallout at residential outdoor receptor is thousand times higher than maximum permissible limits (0.01 mt/km^2/m) developed in Australia (Ferrari, 2000) and also shown significant increase within a decade (Thakur and Deb, 1999). Dust fallout levels in Siltara industrial area has shown higher deviation pattern in annual geometrical mean compared to that in Urla Industrial area. However, Urla Industrial area has shown higher dust fallout in all monitoring locations. Annual mean of dust fallout measured at 3ft height on paved road has

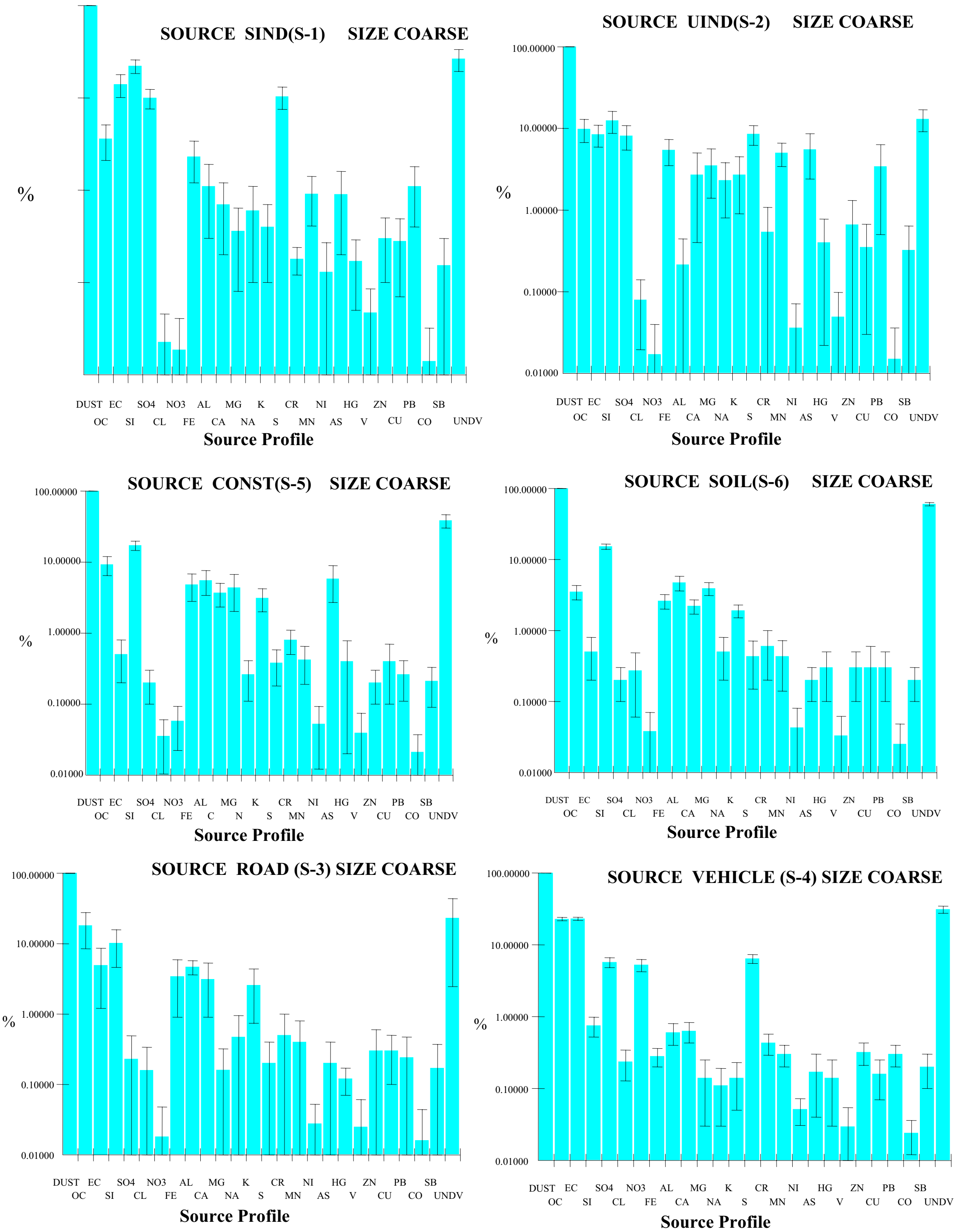

Fig. 3. Profiles of identified sources developed by Chemical Mass Balance Model (CMB 8).

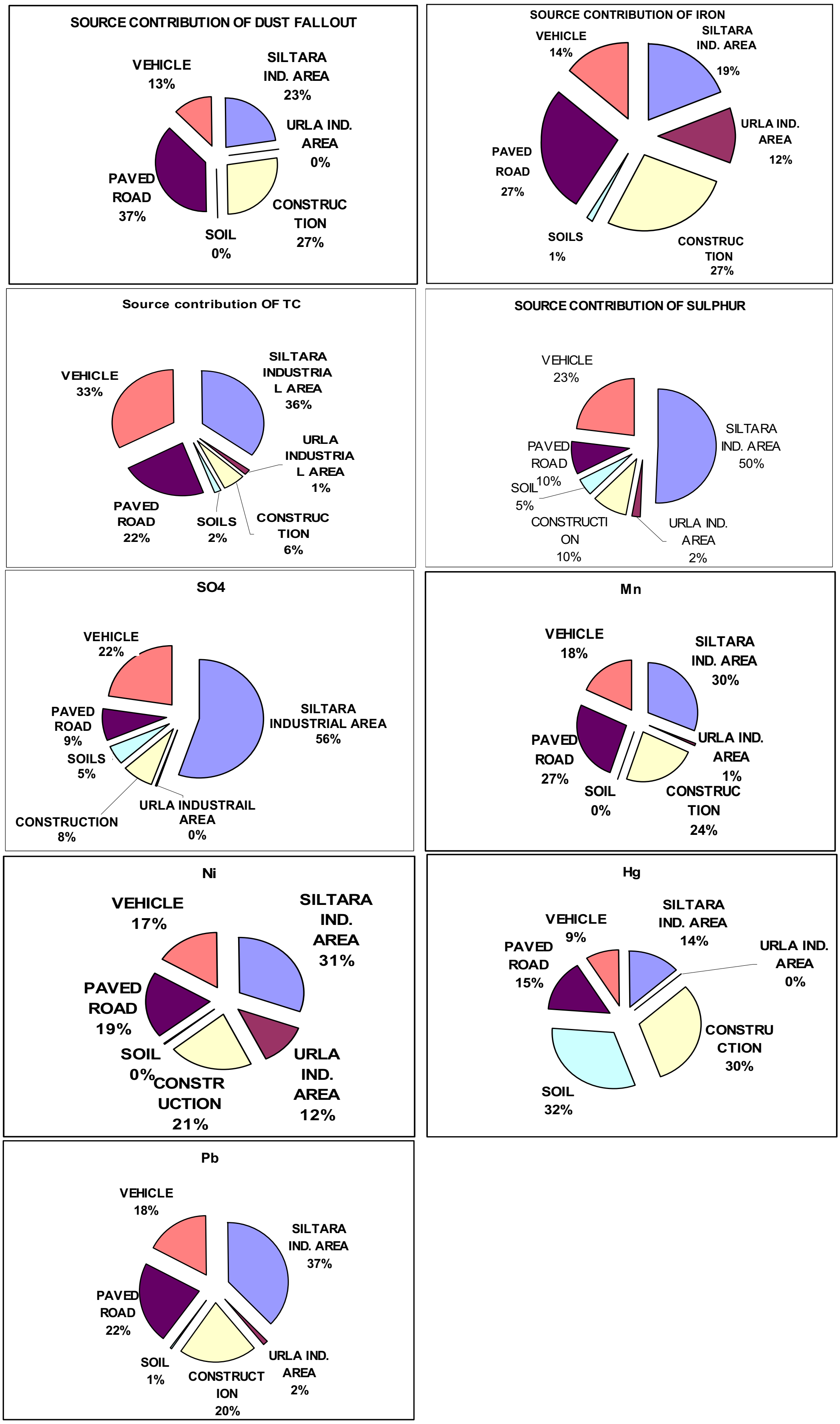

Fig. 4. Relative source contribution estimates of atmospheric dust fallout (Annual average) at Birgaon-residential area of Raipur, India.

shown higher dust fallout in all monitoring locations. Annual mean of dust fallout measured at 3ft height on paved road has also shown comparable levels with that measured in industrial sites due to higher degree of re-suspension of dusts formed during eruption of low quality paved road material. Annual mean of dust fallout at civil construction source site has shown thousand times higher level compared to maximum permissible limits.

Linear regression analyses have shown that receptor site (R-1) is best correlated with Siltara Industrial area (S-1) compared to other sources. Intercept values (Geller *et al.*, 2002) has explained that 27.5% contribution of annual dust fallout at R-1 has been given by Siltara (S-1), while Urla industrial area has shown 4.0% contribution. Other source contributions are: paved road dusts- 44.71% and Construction activity- 30.14%. Dust fallout of paved road has shown dominating relationship with dust fallout of residential outdoor.

Annual mean of selected chemical species measured in dust fallout of S-1 to S-4 has been utilized as source profile for the source apportionment of dust fallout at Birgaon residential outdoor (R-1). Besides, chemical profiles of vehicle exhaust and local soils have also been prepared and used for source apportionment modeling. Output of CMB8 with good fit parameters (chai square- 0.34, R^2- 0.79) has been presented (Fig. 4). Model calculated source profiles have also been presented (Fig. 3). Multiple source contribution has been observed with dominance of paved road. Re-suspension of poor quality road-dust has suppressed the soil dust contribution upto a large extent. Lower contribution of Urla Industrial source compared to Siltara Industrial source has been observed and variation in contribution could be assessed using wind channels of the study region. In contrast to international scenario, vehicle exhaust has shown lower contribution due to predominance of paved road dust source. Results showed clear agreement with those obtained by regression analysis of dust matrix.

Elemental carbon (EC), sulphur and sulphate have shown major contribution from Siltara Industrial area compared to other sources. Even receptor sulphur has shown about 50% share of emissions from Siltara industrial area. Iron has shown different pattern of occurrence at the residential outdoor site. Paved road has shown dominance in iron compared to industrial sites. Paved road has again responded to contribute calcium in receptor dust fallout in equal strength as response of civil construction. In case of manganese contribution, S-1, 3 and 5 have shown similar share with dominance on other source(S-2, 4 and 6). Paved road has shown equivalent contribution with industrial source (S-1). Nickel has shown major contribution from industrial source (S-1) followed by paved road and construction activities. Construction activities (S-5) have shown dominance on mercury contributor (45%) to receptor dust fallout (R-1). 0.02 g Mercury has been reported in one tone of cementitious materials including limestone of the region (ACC, 2007). Occurrence of different pattern of relative contribution estimates of mercury may be due to 4-5 ft height from ground level. This atmospheric layer is mostly affected by local and ground sources. Industrial source (S-1) and paved road has also shown significant relative contribution (20-22%) in mercury concentration. Soils and industrial source (S-2) have not shown any contribution. Lead has shown major contribution (37%) of industrial source (S-1) compared to other sources. Local construction, paved road and vehicle exhaust have also shown significant relative contributions.

In conclusion, dust fallout at outdoor atmospheric level in Birgaon residential area is not only affected by a single source but multiple sources are responsible. Siltara Industrial area, local construction activities and paved road dust has been identified as major precursors of dust fallout in the region. Both tests (regression analysis and receptor modeling) have shown similar pattern of source dominance on receptor dust fallout. Except iron, all other indicator species of industrial emissions (EC, S and SO_4^-) have shown similar pattern of relative contribution estimates in receptor dust fallout.

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REFERENCES

ACC, (2008). *Sustainable Development Report 2007: Strength and Performance*. Associate Cement Company Ltd., Mumbai.

Adachi, K. and Tainosho, Y. (2004). Characterization of Heavy Metal Particles Embedded in Tire Dust. *Environ. Int.* 30: 1009-1017.

Anderson, M.J., Daly, E.P., Miller, S.L. and Milford, J.B. (2002). Source Apportionment of Exposures to Volatile Organic cCompounds II. Application of Receptor Models to TEAM Study Data. *Atmos. Environ.* 36:3643-3658.

Arslan, H. (2001). Heavy Metals in Street Dust in Bursa, Turkey. *J. Trace Microprobe Tech.* 19: 439-445.

Babko, A.K. and Pilipenko, A.T. (1976). P*hotometric Analysis Methods of Determining Non-metals.* Mir Publications, Moscow, p.28-30.

Barceloux, D.G. (1999). Vanadium. *Clin. Toxicol.* 37: 265-278.

Bassett, J., Mendham, J., Jeffery, G.H. and Denney, R.C. (1989). *Vogel's Textbook of Quantitative Chemical Analysis.* (5^{th} Ed.) ELBS/Longman, England, p. 487.

Begum, A.B.; Biswas, S.K. and Hopke, P.K. (2007). Source Apportionment of Air Particulate Matter by Chemical Mass Balance (CMB) and Comparison with Positive Matrix Factorization (PMF) Model. *Aerosol Air Qual. Res.* 7: 446-468.

Bohm, G.M. and Saldiva, H.N. (2000). Urban Air Pollution and Health Effect: A Summary of Evidences Collected in SaoPaulo, BRAZIL. Iniciativa De Aire Limpio, School of Medicine, University of Sao Paulo, Brazil.

Chowdhury, Z., Zheng, M. and Russell, A.G. (2004). Source Apportionment and Characterization of Ambient Fine Particles in Delhi, Mumbai, Kolkata, and Chandigarh. Draft Final Report to the World Bank. Prepared by Georgia Institute of Technology, Atlanta, GA.

ChristianM G.D. (2003). *Analytical Chemistry*. (6^{th} Ed.) John Wiley, New Jerssey.

Cooper, J.A. and Watson, J.G. (1980). Receptor Oriented Methods of Air Particulate Source Apportionment. *J. Air Pollut. Contr. Assoc.* 30: 1116-1125.

CPCB, (2007). A Draft of Conceptual Guidelines and Common Methodology for Air Quality Monitoring, Emission Inventory and Source Apportionment Studies for Indian Cities. Central Pollution Control Board, New Delhi. www.cpcb.nic.in/Air/sourceapportionmentstudies.html.

CPCB, (2007a). Model Standard Operating Procedures (SOPs) for Sampling and Analysis: Air Quality Monitoring, Emission Inventory and Source Apportionment Studies for Indian Cities. Central Pollution Control Board. www.cpcb.nic.in/Air/source apportionmentstudies.html.

Davis, A.P., Shokouhian, M. and Ni, S. (2001). Loading Estimates of Lead, Copper, Cadmium, and Zinc in Urban Runoff from Specific Sources. *Chemosphere*. 44: 997-1009.

Dubey, N. and Pervez, S. (2008). Investigation of Variation in Ambient PM_{10} Levels within an Urban-Industrial Environment. *Aerosol Air Qual. Res.* 8: 54-64.

Dundar, M.S. (2006). Vanadium Concentrations in Selected Outdoor Dust Particles. *Environ. Monit. Assess.* 123: 345-350.

Dundar, M.S. and Altundag, H. (2002). Heavy Metal Determination of House Dust in Adapazari, Turkey, after Earthquake. *Trace Elem. Electrolytes* 19: 55-58.

Dundar, M.S. and Deryaoglu, N. (2005), Heavy Metal Determinations in Outdoor Atmospheric Dust Depositions. *Fresenius Environ. Bull*. 14: 185-188.

Dundar, M.S. and Pala, M.F. (2003). Monitoring of Lead, Zinc, Cadmium, Nickel, Chromium and Copper in Street Dust Samples in Adapazari, Turkey, after Earthquake. *Trace Elem. Electrolytes.* 20: 104-107.

Ferrari, L. (2000). Dust Nuisance: An Australian Perspective. http://www.mfe.govt.nz/publications/air/workshop-presentations/l-ferrari-dust-may00.pdf.

Friedlander, S.K. (1973). Chemical Element Balances and Identification of Air Pollution Sources. *Environ. Sci. Technol.* 7: 235-240.

Gadkari, N. and Pervez, S. (2008). Source Apportionment of Personal Exposure of Fine Particulates among School Communities in India. *Environ. Monit. Assess.* 142: 227-241.

Gadkari, N. and Pervez, S. (2007). Source Investigation of Personal Particulates in Relation to Identify Major Routes of Exposure among Urban Residentials. *Atmos. Environ.* 41: 7951-7963.

Geller, M.D., Chang, M., Sioutas, C., Ostro, B.D. and Lipsett, M.J. (2002). Indoor-Outdoor Relationship and Chemical Composition of Fine and Coarse Particles in the Southern California Deserts. *Atmos. Environ.* 36: 1099-1110.

Gilbert, R.O. (1987). *Statistical Methods for Environmental Pollution Monitoring*, John Wiley, New York.

Goel, P.K., and Trivedi, R.K. (1998). *An Introduction to Air Pollution.* Techno Science, Jaipur.

Gordon, G.E. (1980). Receptor models. *Environ. Sci. Technol.* 14: 792-800.

Gordon, G.E. (1988). Receptor models. *Environ. Sci. Technol.* 22: 1132-1142.

Hidy, G.M. and Venkataraman, C. (1996). The Chemical Mass Balance Model for Estimating Atmospheric Particle Sources in Southern California. *Chem. Eng. Commun.* 151: 187-209.

Illinois State Water Survey (2003). National Atmospheric Deposition Program 2002 Annual Summary. NADP Data Report 2003-01. Illinois State Water Survey. Champaign, IL.

Katz, M. (1977). *Methods of Air Sampling and Analysis*, American Public Health Association, Washington, D.C.

Kothai, P., Saradhil, I.V., Prathibha, P., Hopke P.K., Pandit, G.G. and Puranik, V.D. (2008). Source Apportionment of Coarse and Fine Particulate Matter at Navi Mumbai, India. *Aerosol Air Qual. Res.* 8: 423-436.

Montaser, A. and Golightiy, D.W. (1987). *Inductive Coupled Plasma in Analytical Atomic Spectrometry*. (2nd Ed.), Wiley-VCH, New York.

Mustard, M.H., Ellis, S.R. and Gibbs, J.W. (1985). Runoff Characteristics and Washoff Loads from Rainfall-Simulation Experiments on a Street Surface and a Native Pasture in the Denver Metropolitan Area, Colorado. U.S. Geological Survey, Open File Report, p. 84-820.

NEERI Report, (1988). Manual on Water and Wastewater Analysis. National Environmental Engineering Research Institute, Nagpur.

Pitt, R.E. (1979). Demonstration of Nonpoint Pollution Abatement through Improved Street Cleaning Practices. EPA-600/2-79-161. Environmental Protection Agency. Cincinnati, USA EPA.

Pitt, R.E. and Amy, G. (1973). Toxic Materials Analysis of Street Surface Contaminants. EPA-R2-73-283. Environmental Protection Agency. Washington, DC.

Quraishi, Y.F. and Pandey, G.S. (1993). Exposure of Steel Plant Related Dusts in Domestic Environments in Bhilai Residential Areas. *Indian J. Environ. Prot.* 13: 580-583.

Quraishi, Y.F. and Pandey, G.S. (1995). Bronchial Contamination with Toxic Metals in Mineral Based Industrial Areas of India. *Environ. Geochem. Health.* 17: 25-28.

Rogge, W.F, Hildemann, L.M, Mazurek, M.A., Cass, G.R. and Simoneit, B.R. (1993). Sources of Fine Organic Aerosol: 3. Road Dust, Tire Debris, and Organometallic Brake Lining Dust: Roads as Sources and Sinks. *Environ. Sci. Technol.* 27: 1892-1904.

Roosli, M. (2001). Spatial Variability of Air Pollutants in the Basel Area and Carcinogenic and Non-carcenogenic Health Risk. Ph.D. Thesis, University of Basel, Basel, Switzerland.

Sartor, J.D. and Boyd, G.B. (1972). Water Pollution Aspects of Street Surface Contaminants. EPA-R2-72-081. Environmental Protection Agency, Washington.

Sax, I.N. and Richard, J.L. (1984). *Dangerous Properties of Industrial Material*s (7th Ed.), Vol-I, Van Nostrand Reinhold, New York

Saxena, D.K., Singh, S. and Srivastava, K. (2008). Atmospheric Heavy Metal Deposition in Garhwali Hill Area (India): Estimation Based on Native Moss Analysis. *Aerosol Air Qual. Res.* 8: 94-111.

Schroder, L.J. and Hedley, A.G. (1986). Variation in Precipitation Quality during a 40-hour Snowstorm in an Urban Environment—Denver, CO. *Int. J. Environ. Stud.* 28: 131-138.

Schroder, L.J., Brooks, M.H., Garbarino, J.R. and Willoughby, T.C. (1987). *The Influence of an Urban Environment in the Chemical Composition of Precipitation, Chemical Quality of Water and the Hydrologic Cycle*, Lewis Publishers, Chelsea, MI.

Sharma, R.K. and Pervez, S. (2003). Enrichment and Exposure of Particulate Lead in a Traffic Environment in India. *Environ. Geochem. Health*. 25: 297-306.

Sharma, R.K. and Pervez, S. (2004). A Case Study of Spatial Variation and Enrichment of Selected Elements in Ambient Particulate Matter around a Large Coal-Fired Power Station in Central India. *Environ. Geochem. Health*. 26: 373-381.

Sharma, R.K. and Pervez, S. (2005). Toxic Metals Status in Human Blood and Breast Milk Samples in an Integrated Steel Plant Environment in Central India. *Environ. Geochem. Health*. 27:39-45.

Smolders, E. and Degryse, F. (2002). Fate and Effect of Zinc from Tire Debris in Soil. *Environ. Sci. Technol.* 36: 3706-3710.

Thakur, M. and Deb, M.K. (1999). Lead Levels in the Airborne Dusts Particulates of an Urban City of Central India. *Environ. Monit. Assess.* 62: 305-316.

Turkoglu, O., Saracoglu, S. and Soylak, M. (2003). Trace Metal Levels in Soil Samples from Crossroads in Kayseri-Ankara Motorway. *Trace Elem. Electrolytes.* 20: 225-229.

Tuzen, M. (2003). Investigation of Heavy Metal Levels in Street Dust Samples in Tokat. Turkey. *J. Trace Microprobe Tech.* 21: 513-521.

USEPA, (2003). Fourth External Review Draft of Air Quality Criteria for Particulate Matter (June 2003). EPA/400/3-91/003Ad, Environmental Protection Agency, Research Triangle Park A.C.

Watson, J.G. (1984). Overview of Receptor Model Principles. *J. Air Pollut. Contr. Assoc.* 34: 619-23.

Watson, J.G., Cooper, J.A. and Huntzicker, J.J. (1984). The Effective Variance Weighting for Least Squares Calculations Applied to the Mass Balance Model. *Atmos. Environ.* 18: 1347-1355.

Watson, J.G., Robinson, N.F., Lewis, C. and Coulter, T. (1997). Chemical Mass Balance Receptor Model Version 8 (CMB8): Users Manual. Document Number 1808-1D1, Desert Research Institute, US Environment Protection Agency (USEPA).

Watson, J.G., Robinson, N.F., Fujita, E.M., Chow, J.C., Pace, D.G., Lewis, C. and Counter, T. (1998). CMB8 Application and Validation Protocol for $PM_{2.5}$ and VOCs. Document Number 1808-2 D1, Desert Research Institute, US Environment Protection Agency (USEPA).

Wieringa, M.H., Weyler, J.J., Van Bastelaer, F.J., Nelen, V.J.,

Van Sprundel, M.P. and Vermeire, P.A. (1997). Higher Asthma Occurrence in an Urban than a Suburban Area: Role of House Dust Mite Skin Allergy. *Eur. Respir. J.* 10: 1460-1466.
Yakovleva, E., Hopke, P.K. and Wallace, L. (1999). Receptor Modeling Assessment of Particle Total Exposure Assessment Methodology Data. *Environ. Sci. Technol.* 33: 3645-3652.
Zhang, Y., Quraishi, T. and Schauer, J.J. (2008). Daily Variations in Sources of Carbonaceous Aerosol in Lahore, Pakistan during a High Pollution Spring Episode. *Aerosol Air Qual. Res.* 8: 130-146.

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