

# Source apportionment of arsenic in atmospheric dust fall out in an urban residential area, Raipur, Central India

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**Abstract.** The components and quantities of atmospheric dust fallout have been reported to be the pollution indicator of large urban areas. The multiplicity and complexity of sources of atmospheric dusts in urban regions 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 Arsenic in urban dust fallout in an urban-industrial area, Raipur, India. Source-receptor based representative sampling plan using longitudinal study design has been adopted. 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. Source apportionment has been done using Chemical Mass Balance (CMB 8). Good fit parameters and relative source contribution has been analyzed and documented. Dominance of coal fired industries sources on arsenic levels measured at selected ambient residential receptors compared to line sources has been observed. Road-traffic has shown highest contribution of dust at indoor houses and out door-street automobile exhaust has shows highest contribution for arsenic. The results of CMB output and regression data of source-receptor dust matrices have shown comparable pattern.

## 1 Introduction

Atmospheric particulate pollutants, specifically heavy metals and trace elements derived from different anthropogenic sources, induce a variety of health effects which are currently considered as major problems in the highly urbanized regions of the world. Among the trace elements of airborne

particulate matter, arsenic is the commonly known toxic element which causes adverse effects on human health (Deb and Thakur, 2002). Arsenic occurs naturally in a wide range of minerals, but its distribution in the environment is due to emission of fossil fuel combustion, industrial activities, widespread use of pigments, pesticides and other human activities reported in recent years (Deb and Thakur, 2002; Tsai et al., 2003; National research council report 1999 and 2001, NRC 1999 and 2001). Arsenic concentration in urban environment varies considerably in roadside soils (Chirenje et al., 2001). Urban soils are significantly more heterogeneous than undisturbed soils and also human activity plays a dominant role in the changing of these soils (Chirenje et al., 2003; Davis et al., 1987; Maiti et al., 2010). Urban particulates can be emitted directly to the atmosphere through combustion processes and it is considered that traffic is one of the main sources of particulate pollution (Pandey and Patel, 1998; Pio et al., 1998; Kleeman and Cass, 1998). Studies on urban atmospheric particulate matter and on street sediments were carried out in some Chinese cities (Shu et al., 2001; Li et al., 2001). These results highlight the need to investigate the near-ground deposition of particulate matter with regard to impact on humans and plants. The arsenic species is in the form of arsenite, which is the most prevalent form of arsenic in some ground waters the dermal uptake for arsenite during one bath could increase to 1.1  $\mu\text{g}$  arsenite (Ngugen et al., 2009).

The highest average concentration of arsenic in particulates deposited on canopy leaves found in C.I.T. Road is 39  $\text{mg g}^{-1}$ , followed by Shymbazar, M. G. Road and Seal-daha having 29, 29 and 28  $\text{mg g}^{-1}$  respectively. These values are higher than the arsenic concentration found in other sites like Chingregghata, Maidan and Moulali area. But in case of street dust, the occurrence of arsenic does not show such variation. Though it shows maximum concentration at C.I.T Road having a significant value of 18.71  $\text{mg g}^{-1}$ , other sites show moderate arsenic ranging between 2 and



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10 mg g<sup>-1</sup>. These levels of arsenic concentration are also relevant with the values obtained by Chakraborty et al. (1998), i.e. 2–29 mg g<sup>-1</sup> in the city. This type of arsenic concentration in dust fallout like in street dust, is less compared to the medium arsenic concentration range of 32–113 mg g<sup>-1</sup> measured in residential roadside dust in Chihuahua, Andrea in North Mexico 1999.

Mercury and arsenic, occurring in both organic and inorganic forms in natural environment, are toxic elements for human health that persist and cycle in the environment as a result of natural and anthropogenic activities (Sörös et al., 2003; Walcek et al., 2003). Anthropogenic sources are mostly transportation, mining, smelting, refining, waste incineration, and fossil fuel combustion (Al-Momani et al., 1995; Bem et al., 2003; Kim et al., 2002; Ozaki et al., 2004; Tasdemir and Kural, 2005). Fossil fuels, combusted largely during industrialization and urbanization, contain various heavy metals, such as lead, zinc, mercury and arsenic. It has been reported that gasoline contains 0.2–3.3 ng g<sup>-1</sup> mercury (Liang et al., 1996) and 30–120 ng g<sup>-1</sup> arsenic (Ozaki et al., 2004). The average contents of mercury and arsenic in the coal of China are 7.79 mg g<sup>-1</sup> (Lu, 2004, Liu, 2007) and 0.22 mg g<sup>-1</sup> (Wang and Shen, 1999), respectively. Coal combusted in Baoji and other cities of central Shaanxi is mainly from the Weibei coalfield. The contents of mercury and arsenic in this coal range from 0.03 to 1.67, and 0.63 to 86.48 mg g<sup>-1</sup>, with averages of 0.39 and 7.60 mg g<sup>-1</sup>, respectively (Lu et al., 2003). Mercury and arsenic contained in the fossil fuels are emitted into the environment during the combustion of fossil fuels (Ozaki et al., 2004).

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 (Saxena et al., 2008; Quraishi and Pandey, 1995; Sharma and Pervez, 2005, 2003, Bohm and Saldiva, 2000; Goel and Trivedi, 1998). Due to higher settling tendency of bigger particles of dust fallout fraction near emission sources on a regional scale, researchers have made classification of its reception pattern as ambient-outdoor, street-outdoor and indoors dust fallout (Dubey and Pervez, 2008; Quraishi and Pandey, 1993; Sharma and Pervez, 2004; Gadkari and Pervez, 2007).

The presented work has been focused on source apportionment of arsenic in dust fallout in selected classified urban receptor of Raipur City, 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 deposit regions has been utilized to identify possible sources/routes of dust transport to a receptor region. Chemical mass balance (CMB8,) has been executed to investigate source contribution estimates of dust fallout in relation to source signature of arsenic in a specific ambient-outdoor receptor located in a residential area.

## 2 Materials and method (study design, sampling plan and data analysis)

### 2.1 Study design

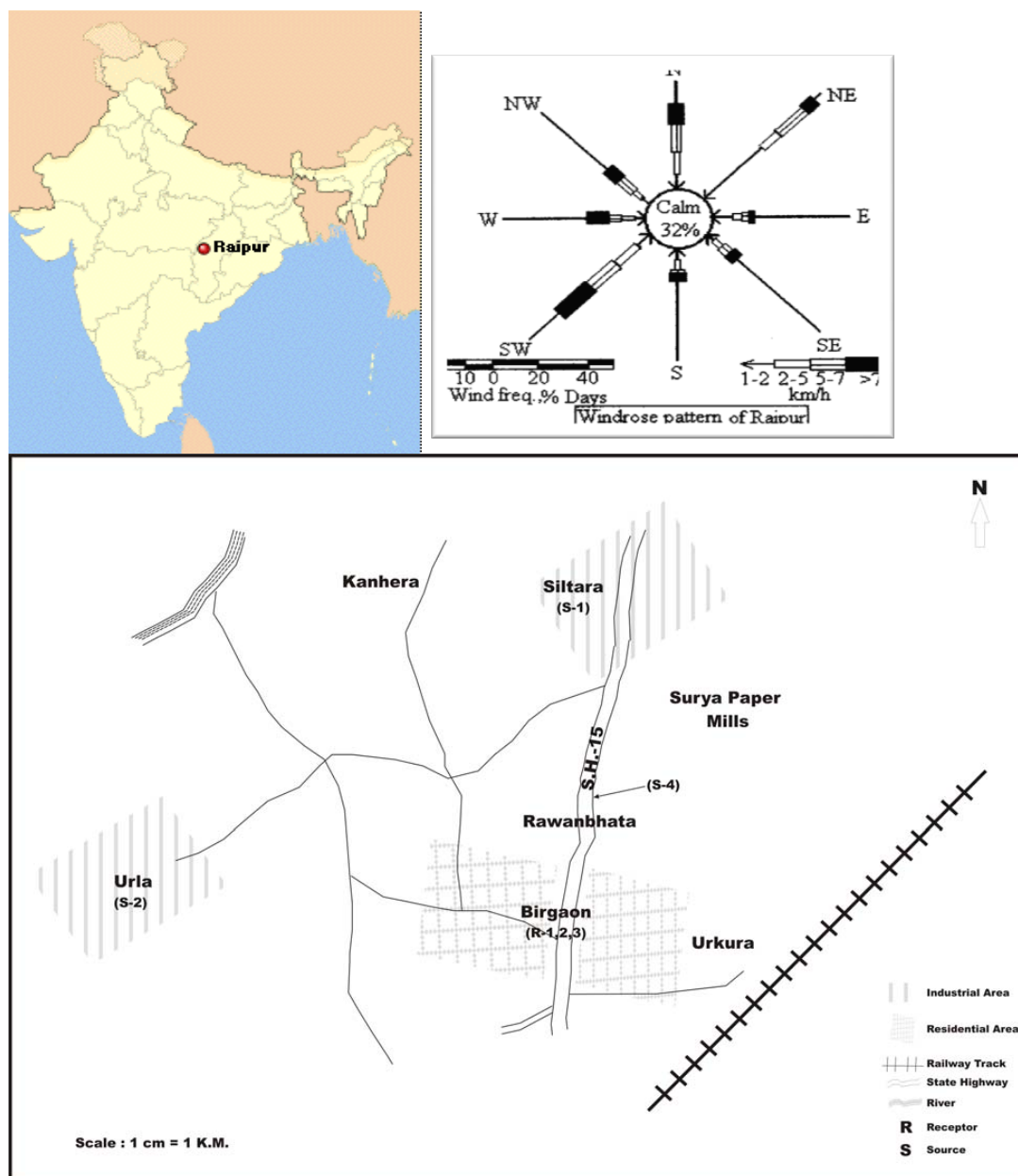
The study was undertaken in an urban area. The goal of the study is to evaluate relative source contribution estimates of various routes of arsenic in dust fallout in urban residential environment. The objectives here are: (1) To measure and characterize dust fallout and arsenic at identified sources (2) to analyze statistically, the relationship between dust fallout measurements of source-routes and residential-receptors and (3) to carryout apportionment of arsenic in dust fall at classified 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 along with 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, wind rose and wind channel has been shown in Fig. 1.

#### 2.1.1 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 year 2007. Source apportionment study of arsenic in 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). Ambient-outdoor atmospheric level has been decided for measurement of dust fallout at identified sources of dust emissions. In case of residential-receptor, three most susceptible atmospheric levels have been chosen, namely ambient-outdoors, house-indoors and local street-outdoors (Table 1).

#### 2.1.2 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), at both source and receptor sites, 5 ft (local street-outdoor) and 1 ft (indoor-house) at receptor sites. Sampling at local-outdoor (5 ft height) has been chosen for measurement at construction activity site. In case of sampling at paved road source (S-3), sampler was



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

installed at the height of 5 ft at major cross road passing near to the residential colony. 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).

As far as soil chemical profile (S-6) is concern, samples of soils (1 kg) have been collected from open land of residential colony. Soil samples were collected after removing surface

soils up to 6 cm (to avoid plant and animal organic, inorganic and microbial contamination on the surface soil) depth and sent to laboratory. Soil has been smashed in a milling machine and blown in a closed glass chamber (size 1.5 m<sup>3</sup>) using a pressure fan. The dust collecting jars has been placed in the chamber and collected dust during dispersion of soil dusts in the chamber (Gadkari and Pervez, 2008). Black smoky dust emitted and deposited in automobile exhaust silencers of diesel fuel based heavy duty trucks and petrol based cars have been collected and scum were mixed together for development of chemical profile of automobile source (S-5).

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

Site 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	12 samples throughout the sampling year (one in each month)
(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	
(S-4)	Civil construction	Area	Ambient-outdoor	Dusts emitted from handling of raw materials used in civil construction site	
(S-5)	Automobile	Point	Emission outlet	Mixed dust fraction emitted from silencer of truck, cars and two wheelers	
(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)
(R-2)			House-indoor		
(R-3)			Out door-street		

Vehicles have been selected randomly which mostly passes through that road junction. About 5–10 g of exhaust emitted black smoky dust has been collected. Frequency of sampling was 12 (one in each month) at each source-receptor site throughout the sampling period (December 2007 to November 2008).

The dust fall rate was calculated for each site using the following equation (Kikuo, 1977):

$$R = 1 : 273(W/D)^2 \times (30/N) \times 10^4 \quad (1)$$

where,

$R$  – Dust fall rate (metric tonne (mt)  $\text{km}^{-2} \text{month}^{-1}$ );

$W$  – the total weight of dust fall-out in the collecting container (g);

$D$  – the diameter of the dust collecting container (cm);

$N$  – the number of days of collection of sample.

## 2.2 Chemical analysis of dust fallout

Specialized cleaning and sampling techniques were used during all stages of sample collection to prevent contamination. All containers and equipment used for sampling were cleaned using a dilute liquid soap followed by a hydrochloric acid solution and multiple rinses in ultra pure, deionized (DI) water, following standard protocols. The dust fallout after the sampling immediately transferred to the laboratory. The samplers were washed with double distilled water and filtered by using wattman filter paper no. 42 in pre-washed polyethylene bottles. The bottles were filled up to neck and

**Table 2.** Yearly average dust fallout ( $\text{mt km}^{-2} \text{ month}^{-1}$ ) monitored in selected classified receptor and source sites.

Ambient-outdoor (R-1)		House indoors (R-2)		Street outdoors (R-3)	
77.5919 ± 25.4883 (51.784–119.64)		14.3144 ± 2.3882 (12.342–18.923)		84.2911 ± 22.3552 (61.56–143.56)	
(0.0641 ± 0.033) <sup>a</sup> (0.0414–0.0957) <sup>b</sup>		(0.0442 ± 0.0284) <sup>a</sup> (0.029–0.082) <sup>b</sup>		(0.0309 ± 0.0324) <sup>a</sup> (0.013–0.112) <sup>b</sup>	
(S-1)	(S-2)	(S-3)	(S-4)	(S-5)	(S-6)
181.186 ± 77.974 (131.51–391)	217.429 ± 24.414 (178.54–245.29)	141.435 ± 18.324 (122.73–186.25)	87.845 ± 16.366 (67.71–116.54)	ND	ND
(0.0089 ± 0.001) <sup>a</sup> (0.007–0.019) <sup>b</sup>	(0.0041 ± 0.0037) <sup>a</sup> (0.002–0.016) <sup>b</sup>	(0.0014 ± 0.00038) <sup>a</sup> (0.0009–0.002) <sup>b</sup>	(0.0006 ± 0.002) <sup>a</sup> (0.0005–0.0009) <sup>b</sup>	(0.0043 ± 0.002) <sup>a</sup> (0.003–0.013) <sup>b</sup>	(0.0017 ± 0.001) <sup>a</sup> (0.0005–0.001) <sup>b</sup>

<sup>a</sup> Values in parenthesis are annual average Arsenic concentration ( $\text{mt km}^{-2} \text{ month}^{-1}$ ).

<sup>b</sup> Values in parenthesis are minimum and maximum levels throughout sampling period.  
Abbreviation: mt – metric tone, ND – Not measured

then added few drops of acid mixture (Sulfuric acid  $\text{H}_2\text{SO}_4$  and Hydrochloric acid  $\text{HCl}$ , 1:1) to maintain the pH about 1–2. The dust fall which is collected on filter paper was stored in zippered polyethylene. All collected samples stored at 5 °C or less until chemical analysis. The samples were taken for digestion in the Teflon digestion bomb and added nitric acid ( $\text{HNO}_3$ ) and hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) (3:1). The Teflon bomb was then kept in an electric oven at 60 °C for five hour. After five hours Teflon bomb was cooled, content was filtered in a volumetric flask and washed with dilute nitric acid ( $\text{HNO}_3$ ). Final volume of the digested sample was made to 25 ml using distilled water. Digested samples and soluble fraction of dust fallout measured during field sampling were analyzed for total As content using inductive coupled plasma-atomic emission spectrophotometer (ICP-AES) (JOBIN-YVON HORIBA ICP Spectrometer Version 3.0). Arsenic analysis was carried out at a wavelength of 189.042 nm to avoid spectral and chemical interferences. Calibration of instrument was done using Merck standard ICP solution of concentration range 0.1–10 ppm. The power used for analysis is 1200 W; plasma gas flow rate is  $121 \text{ min}^{-1}$ .

### 2.3 Data analysis

Measurement data of dust fallout and particulate arsenic has been documented as geometrical mean and standard deviation of longitudinal measurements of each monitoring site and presented in Table 2. Regression analysis between annual mean of dust fallout measured at defined receptor site (local-outdoor, indoor and street 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) (Table 4) 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 (Table 3). 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 the contributing 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. 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.

Geometric mean and standard deviation values of chemical parameters have been utilized for the concentration and 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 and 4.

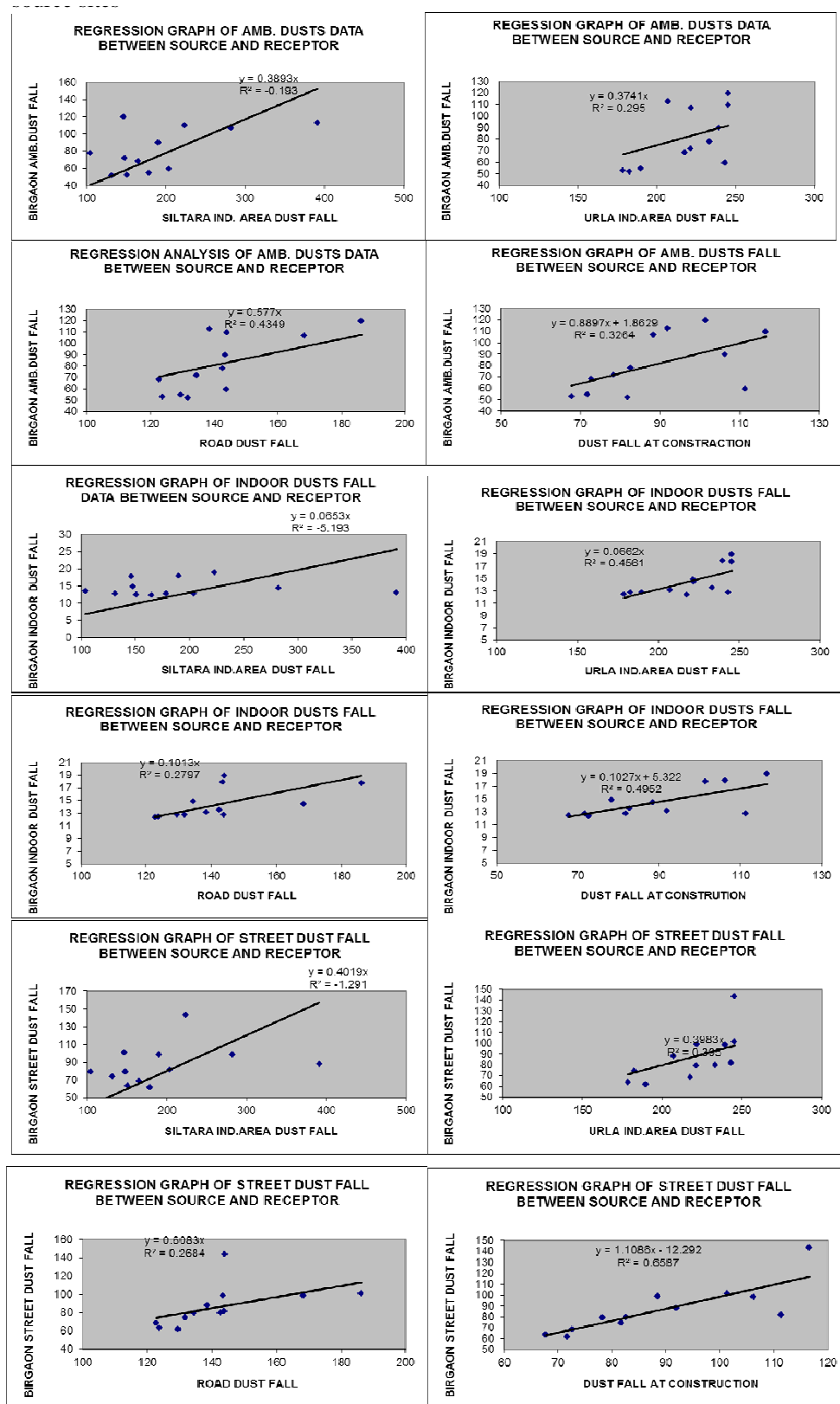


Fig. 2. Regression analysis between selected dust fallout receptors and dust fallout at identified source sites.

**Table 3.** Good fit parameters of CMB execution output results for selected receptors.

SUB	$R^2$	CHI SQUARE	TSTAT					
			(S-1)	(S-2)	(S-3)	(S-4)	(S-5)	(S-6)
AMBIENT	0.79	0.34	1.6924	1.0201	0.8417	–	1.6504	0.9738
STREET	0.51	3.75	3.8964	1.672	0.207	–	2.414	0.141
INDOOR	0.73	1.63	2.235	2.084	0.425	–	3.529	0.301

**Table 4.** Source profile for all sources.

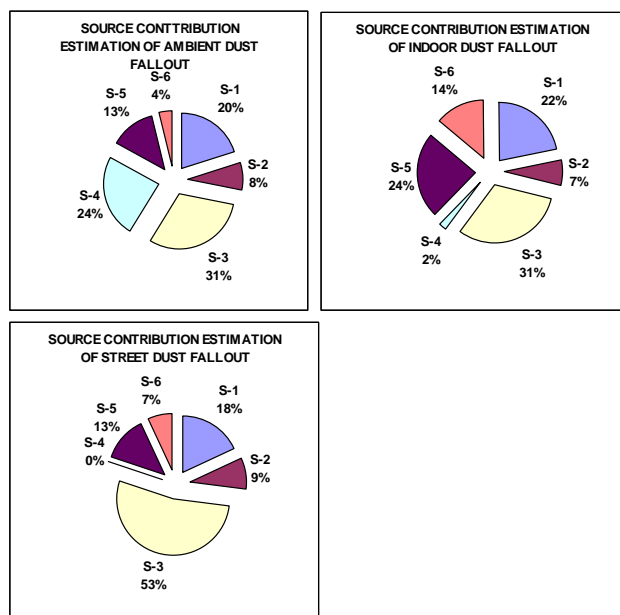
PNO	SID	SIZE	OC	OCU	EC	ECU	SI	SIU	SO4	SO4U	CL	CLU	NO3
Y1	SIND	COARSE	0.03597	0.01495	0.1396	0.0387	0.221	0.037	0.09972	0.02379	0.000226	0.00023	0.000186
Y2	UIND	COARSE	0.098	0.031	0.084	0.025	0.124	0.037	0.081	0.027	0.000794	0.000599	0.000171
Y3	CONST	COARSE	0.0923	0.0276	0.005	0.003	0.1718	0.0257	0.002	0.001	0.000353	0.000249	0.000576
Y4	SOIL	COARSE	0.035	0.008	0.005	0.003	0.152	0.013	0.002	0.001	0.002723	0.002121	0.000379
Y5	ROAD	COARSE	0.1802	0.0959	0.049	0.037	0.1014	0.0554	0.0023	0.0026	0.001583	0.001792	0.00018
Y6	VEHICLE	COARSE	0.2277	0.0123	0.23	0.012	0.0075	0.0023	0.057	0.009	0.002351	0.001075	0.05229
NO3U	FE	FEU	AL	ALU	CA	CAU	MG	MGU	NA	NAU	K	KU	S
0.00022	0.023	0.011	0.011	0.008	0.007	0.005	0.0036	0.0028	0.006	0.005	0.004	0.003	0.103
0.000226	0.054	0.019	0.00213	0.0023	0.027	0.023	0.035	0.021	0.023	0.015	0.027	0.018	0.085
0.000355	0.048	0.02	0.055	0.021	0.0367	0.0134	0.0436	0.0234	0.0026	0.0015	0.031	0.011	0.0038
0.000321	0.026	0.006	0.047	0.011	0.022	0.005	0.039	0.008	0.005	0.003	0.019	0.0039	0.0043
0.000296	0.034	0.025	0.0466	0.0106	0.031	0.022	0.0016	0.0016	0.0047	0.0048	0.0255	0.0181	0.002
0.010195	0.0028	0.0008	0.006	0.002	0.0063	0.002	0.0014	0.0011	0.0011	0.0008	0.0014	0.0009	0.064
SU	CR	CRU	MN	MNU	NI	NIU	AS	ASU	HG	HGU	V	VU	ZN
0.028	0.0018	0.0006	0.0091	0.005	0.0013	0.0014	0.009	0.001	0.0017	0.0012	0.000471	0.000382	0.003
0.023	0.00537	0.0054	0.05	0.016	0.00036	0.00035	0.004	0.004	0.00399	0.00377	0.000491	0.000491	0.0066
0.002	0.008	0.003	0.0042	0.0023	0.000523	0.000402	0.0014	0.0006	0.002	0.0038	0.000392	0.00035	0.002
0.0028	0.006	0.004	0.0043	0.0029	0.000426	0.000378	0.0017	0.001	0.003	0.002	0.000329	0.000288	0.003
0.002	0.005	0.005	0.004	0.004	0.000277	0.000245	0.0014	0.0003	0.0012	0.0005	0.000249	0.00036	0.003
0.009	0.0043	0.0014	0.003	0.001	0.000514	0.000207	0.0043	0.002	0.0014	0.0011	0.000295	0.000245	0.0032
ZNU	CU	CUU	PB	PBU	CO	COU	SB	SBU	UNDV	UNDVU			
0.002	0.0028	0.0021	0.011	0.007	0.00014	0.00018	0.00153	0.00146	0.264	0.0706			
0.0065	0.0035	0.0032	0.034	0.029	0.00015	0.00021	0.00322	0.003151	0.130108	0.03913			
0.001	0.004	0.003	0.0026	0.0015	0.00021	0.00016	0.0021	0.0012	0.3824	0.0809			
0.002	0.003	0.003	0.003	0.002	0.00025	0.00023	0.002	0.001	0.6015	0.0305			
0.003	0.003	0.002	0.0024	0.0023	0.00016	0.00028	0.0017	0.002	0.2302	0.2057			
0.0011	0.0016	0.0009	0.003	0.001	0.00024	0.00012	0.002	0.001	0.3103	0.0353			

### 3 Results and discussion

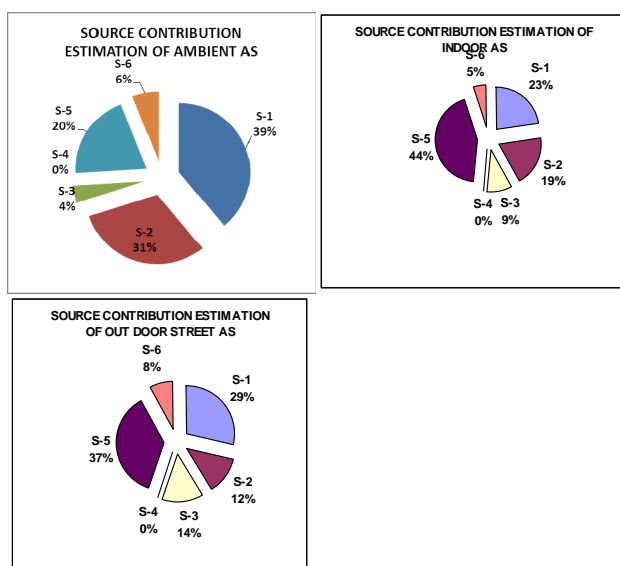
#### 3.1 Annual flux and rate of dust fallout

The total annual flux of airborne dust particulate has been calculated on the basis of month wise measurements of dust fall rate at different sources and receptor during December 2007–November 2008. All the sites have shown thousand times higher annual dust fall rate compared to prescribed standard of  $0.01 \text{ mt km}^{-2} \text{ month}^{-1}$  (Ferrari, 2000). The monthly dust fall rate were found to be in the range  $67.71\text{--}391.01 \text{ mt km}^{-2} \text{ month}^{-1}$  for all six source sites and the receptor site has shown the range  $51.78\text{--}119.64 \text{ mt km}^{-2} \text{ month}^{-1}$  at ambient-outdoor level,  $61.56\text{--}143.56 \text{ mt km}^{-2} \text{ month}^{-1}$  at outdoor-street and  $12.342\text{--}18.923 \text{ mt km}^{-2} \text{ month}^{-1}$  in house-indoors of resi-

dential area during the sampling period of 12 month. The lowest rate of dust fall in source sites was found at construction (S-4) in summer and the highest at Siltara industrial area (S-1) in spring and at receptor area (Birgaon) (R-1), the lowest rate found in post-rainy and the highest in winter at ambient-outdoor level. In street-outdoor level, lowest rate was found in post-rainy and the highest in winter season. Indoor-house has shown lowest dust fall in summer and the highest winter season. The geometric mean of dust fall-out rate ( $\text{mt km}^{-2} \text{ month}^{-1}$ ) of 12 sampling months at different sampling sites were found to be:  $181.19 \pm 77.97$  (S-1),  $217.43 \pm 24.41$  (S-2),  $141.44 \pm 18.32$  (S-3),  $87.85 \pm 16.366$  (S-4) and for receptor site (R-1), ambient-outdoor level have shown  $77.59 \pm 25.49$ , street-outdoor  $84.29 \pm 22.35$  and house-indoor  $14.31 \pm 2.39$ . On the basis of monthwise dust fall rate, the highest total flux was observed to be measured



**Fig. 3.** Relative source contribution estimation of dust fall out at selected classified atmospheric levels at receptor.



**Fig. 4.** Relative source contribution estimation of particulate arsenic at selected classified atmospheric levels at receptor.

at (S-2) with an amount of  $2624.78 \text{ mt km}^{-2} \text{ yr}^{-1}$ . The values of annual flux in the other sources, viz. (S-1), (S-3) and (S-4) were  $2313.91$ ,  $1709.1$  and  $1070.29 \text{ mt km}^{-2} \text{ yr}^{-1}$ , respectively. Linear regression analyses have shown that receptor site (Birgaon) is best correlated with Road dust fall (S-4) compared to other sources at ambient, street and indoor level (Fig. 2). This has been proved by the CMB model output results for dust fallout.

### 3.2 Arsenic levels in airborne dust fallout

The analyses on month wise and site wise (Chakraborty et al., 1998), arsenic concentration in  $\text{mt km}^{-2} \text{ month}^{-1}$  has been calculated, and annual site wise flux of As in  $\text{mt km}^{-2} \text{ yr}^{-1}$  at different sites for the whole study period have also been evaluated and presented in Table 2. Month wise variation of flux of Arsenic in the airborne dust fall ( $\text{mt km}^{-2} \text{ month}^{-1}$ ) for 12 sampling months at different sampling sites were observed to be in the range:  $0.0089 \pm 0.001$  in (S-1),  $0.0041 \pm 0.0037$  in (S-2),  $0.0014 \pm 0.0038$  in (S-3),  $0.0006 \pm 0.002$  in (S-4),  $0.0043 \pm 0.002$  in (S-5) and  $0.0017 \pm 0.001$  in (S-6). For receptor site, the arsenic concentrations have been found as:  $0.0641 \pm 0.033$  at ambient-outdoor level,  $0.0309 \pm 0.0324$  at street-outdoor, and  $0.0442 \pm 0.0284$  at house-indoor levels. It has been found that indoor arsenic level (R-2) is high in compared to street out door (R-3). This may due to house hold fuel burning. The concentration of arsenic at (S-1) (Siltara industrial area) ranges between  $0.007\text{--}0.019 \text{ mt km}^{-2} \text{ month}^{-1}$  and at (S-2) (Urla industrial area) it ranges between  $0.002\text{--}0.016 \text{ mt km}^{-2} \text{ month}^{-1}$  dust falls. These are higher than the arsenic concentrations found in other sources viz. (S-3, S-4, S-5 and S-6). The arsenic concentrations for other sources were in the range  $0.0009\text{--}0.002 \text{ mt km}^{-2} \text{ month}^{-1}$  at (S-3),  $0.0005\text{--}0.0009 \text{ mt km}^{-2} \text{ month}^{-1}$  at (S-4),  $0.003\text{--}0.013 \text{ mt km}^{-2} \text{ month}^{-1}$  at (S-5) and  $0.0005\text{--}0.001 \text{ mt km}^{-2} \text{ month}^{-1}$  at (S-6) of dust matrix. Simultaneously, residential receptor have shown reception of  $0.0414\text{--}0.0957$  at ambient level,  $0.013\text{--}0.112$  at street and  $0.029\text{--}0.082 \text{ mt km}^{-2} \text{ month}^{-1}$  arsenic at house indoor level in dust fall. Due to the maximum precipitation of airborne particulates, as well as highest concentration of arsenic in industrial areas, the flux of arsenic is also maximum in ambient-outdoor level. The next highest flux of dust fall-arsenic has been found at heavy traffic-outdoors. House-indoors of (R-1) has shown the least quantum of arsenic.

### 3.3 Source apportionment studies

#### 3.3.1 Preliminary assessment using regression analysis

The statistical evaluation of contribution of independent source sites to dependent receptors has been reported to given clear agreement with experimental data in earlier studies. Industrial source (S-1) and construction activities (S-4) have shown significant contribution of  $39.29\%$  and  $90\%$ , respectively to dust fallout at ambient-outdoor level (R-1) of residential receptors. Other two sources (S-2 and S-3) have not shown any contribution in dust fallout at ambient level. In case of street-outdoor level, (S-1) has shown  $17\%$  contribution effect while other selected sources have not shown significant contribution. Paved road (S-3) has shown major contribution in dust fallout of local Street-outdoor (R-1). As far as house-indoor levels is concern, paved road (S-3) and



construction activities (S-4) have shown significant contribution effect of 90 % and 62 % , respectively. Inadequate contribution of major industrial site (S-2) might be due to unfavorable prevailing wind channels to residential receptors.

### 3.3.2 Source signatures of dust fallout and arsenic content using receptor model

Source profiles have shown that mean level of arsenic is projected above than 50th percentile in all sources except (S-1). In case of (S-3), it has been projected above than 75th percentile. Arsenic has shown significant level in all source sites. CMB results have shown multiple source contribution with dominance of paved road in dust fall at all classified atmospheric levels of defined receptor. As far as source contribution assessment of dust fallout is concern, paved road (S-3) has shown major contribution in dust fall at all stages i.e. 31 % at (R-1), 53 % at (R-3) and 31 % at (R-2) of Birgaon residential area. Siltara industrial area (S-1) has shown significant contribution at all stages than Urla industrial area (S-2) with 20 % contribution at (R-1). Arsenic source apportionment values have shown different pattern source contribution at different level compared to source signatures of dust fallout. Siltara industrial area (S-1) has shown major contribution (39 %) at ambient level (R-1), because of the emission of coal burning coarse particulate matters which settle down easily at ambient level which contains arsenic. Vehicle exhaust (S-5) has expressed major contribution (44 % and 37 %) at both (R-2) and (R-3) due to the particulate matter which emitted from vehicle can enter the near atmosphere easily and quickly and can show good contribution in arsenic estimation. Lower contribution of Urla Industrial (S-2) source compared to Siltara Industrial (S-1) source has been observed and variation in contribution could be assessed using windrose of the study region. This is due to unwanted wind direction and the fuel used in industry is not coal. In contrast to international scenario, vehicle exhaust has shown significant contribution.

The results of source apportionment of arsenic content of dust fallout have shown that coal combustion activities (S-1) was came out as a significant contributor with 39 % (R-1), 23 % at (R-3) and 29 % at receptor sites (R-3). Vehicle exhaust (S-5) and industrial location of Urla (S-2) have also shown significant contribution in arsenic content of dust fall in all atmospheric levels of residential receptor (R-1, 2, 3). Overall, contrast result of source apportionment of dust fallout and arsenic content of dust fall has been observed.

In this complete study arsenic levels at receptor site are comparatively high than source sites, this is due to the multiple source contribution at receptor site.

## 4 Conclusions

Profuse and highly skewed dust fallout at outdoor and indoor environment of residential receptor site (Birgaon) 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 ( $0.01 \text{ mt km}^{-2} \text{ m}^{-1}$ ) developed in Australia (Ferrari, 2000) and justify the need to develop India standards of dust fallout. On comparison to previous reported data of dust fallout in this region, present levels have shown about 1.2 fold higher concentration. On comparison to fine particulate matter, coarser particle size of dust fallout has played an important role in decreasing the deviation pattern of annual average from geometric mean. Road borne dusts (S-3) have shown major contribution to dust fallout at residential receptors. Siltara industrial area (S-1), construction activities (S-4) and vehicle exhaust (S-5) sources have also shown significant contribution. Siltara industrial area (S-1) has shown significant contribution at all levels of residential receptor (R-1, 2 and 3) compared to Urla industrial area (S-2) due to unfavorable prevailing wind direction. The annual flux of arsenic in the urban city is an alarming amount of 3.896 mt. On comparison to source apportionment of dust fallout, a different pattern of dominance among selected sources to relative source contributions of arsenic content in dust fallout has been observed. Vehicle exhaust and Urla Industrial area along with Siltara industrial site have shown strong contribution in arsenic levels measured in dust fallout of residential receptors. Overall multisource contribution and strong variation in relative source contribution to dust fallout and its arsenic content in urban-residential environment has been obtained.

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