Source Apportionment of Human Exposure to Particulates in Mumbai, India

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Abstract

Human exposure to Respirable Particulate Matter (RPM, particles less than 5 μm in diameter) was assessed for Low-Income Group (LIG) and Middle-Income Group (MIG) respondents who were monitored for 48-hour integrated exposure in Mumbai, India. Using personal samplers, each respondent was sampled once a week on average from October 2002 to January 2003. An activity diary was recorded and a questionnaire survey carried out by the research team to collect information about workplace and home characteristics. For LIG respondent, the average personal exposure to RPM was 186 $\mu g/m^3$ (n = 8, Std. Dev. = 184). For MIG respondent, it was 73 $\mu g/m^3$ (n = 14, Std. Dev. = 39). The Indian National Ambient Air Quality Standard (NAAQS) was exceeded by 86% for LIG respondent. The respirable dust collected on polycarbonate membrane filter was digested and further analyzed for metals using an atomic absorption spectrophotometer. Average lead concentration of 0.284 $\mu g/m^3$ was much below the NAAQS of 1 $\mu g/m^3$. Metals concentration data were used for source apportionment using factor analysis technique. The analysis resulted in three factors, represented by groups of metals associated with industrial, residential and crustal sources for all samples combined. A separate factor analysis resulted in two and three sources for MIG and LIG respondents, respectively. The third LIG source represented metals associated with residential living conditions, such as poor ventilation and burning of low-grade fuel. The ambient air concentration for PM_{10} in the study area was 291 $\mu g/m^3$ (n = 10). Investigation of source apportionment by statistical analysis can quantify contributions of various indoor and outdoor sources to personal exposure, thus assisting policy makers in developing relevant control and planning strategies.

***Keywords*:** Personal exposure; Respirable particulate matter; Low income group; Middle income group.

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INTRODUCTION

Deteriorating air quality in urban areas has become a major public concern worldwide. South Asian cities suffer from extremely high levels of urban air pollution, particularly in the form of small particles. Regionwide, urban air pollution is estimated to cause 250,000 deaths and billions of cases of respiratory illnesses every year (The World Bank, 2005). One study (Brandon and Homman, 1995) has indicated that approximately 50,000 pre-mature deaths in India occurring annually were due to PM_{10} pollution (PM_{10} = particles less than 10 μm in diameter). Studies have shown that particulate matter is the major air pollutant for Mumbai, India's commercial capital and one of the world's major cities (Kulkarni and Patil, 1999).

This paper discusses one of the first studies of its kind conducted in India and may be in the world in which source apportionment was carried out on the basis of personal exposure. Source apportionment analysis of metals was conducted to identify different sources of air pollution and their relative contribution. Through quantification of the contributions of various indoor and outdoor sources to the personal exposure by statistical analysis, source apportionment can be a valuable tool for policy makers in developing planning and control strategies.

In an earlier study, personal exposure to various population subgroups in urban areas was measured (Kulkarni and Patil, 1998). However, source apportionment was not conducted in that study. Many studies on source apportionment of particulates have been conducted abroad (Chow *et al.,* 1999; Watson *et al.,* 1994), as well as a few in India (Sharma and Patil, 1994; Chowdhury, 2004). However they were all on the basis of ambient air particulates. Few data are available on personal exposure to particulates, which are closely associated with the health risks as unlike ambient air measurement, personal exposure is measured very close to the breathing level. A recent study was conducted by the Georgia Institute of Technology in the United States, in collaboration with National Physical Laboratory, the Indian Institute of Technology, the City of Mumbai, and the National Environmental Engineering Research Institute, India in which analysis of ambient $PM_{2.5}$ (particles smaller than 2.5 μm) was carried out using chemical mass balance receptor modeling (Chowdhury, 2004). The results indicate that there is no single dominant source, but sources differ by location and season among the three Indian cities examined.

The objectives of this study, funded by the All India Council for Technical Education (AICTE), Government of India, were to:

1. Assess the human exposure to particulates for the selected population subgroups in Mumbai.
2. Assess the human exposure to toxic/nontoxic metals.
3. Determine source apportionment of human exposure to particulates using factor analysis.
4. Identify the risk factors and propose guidelines for policy making.

STUDY DESIGN

In this study, personal, or human, exposure to RPM was assessed for respondents selected from two population subgroups: Low-Income Group (LIG) and Middle-Income Group (MIG). The respondents were monitored for 48-hour integrated exposure using personal samplers (SKC, USA). The sampling period was October 2002 to January 2003. Each respondent was sampled once a week on average. The respirable dust collected on polycarbonate membrane filter was digested and further analyzed for various metals using atomic absorption spectrophotometer. The data on concentration of these metals were used for determining source apportionment using factor analysis statistical technique. Respirable dust was not analyzed for nonmetals and organic components in this study.

Assuming that the air pollution concentrations are homogeneous both in space and in time, within each microenvironment, the integrated exposure for an individual (i) is computed as the sum of the product of the pollutant level in each microenvironment (j) and the time the individual spent in the microenvironment (Duan, 1980).

$$E_i = \sum_{1}^{J} C_j t_{ij} \tag{1}$$

where:

E_i = integrated exposure of an individual (i) over the time period

C_j = pollutant level experienced in microenvironment (j)

t_{ij} = time spent by individual (i) in microenvironment (j)

J = total number of microenvironments occupied by individual (i) over the time period.

Average exposure of a person is closely related to the integrated exposure and can be computed by dividing it by the averaging time. Average exposure is also called as the time weighted concentration and is measured in $\mu g/m^3$. Different average times are used in the calculation of exposure to air pollution. For example, total daily exposure often refers to 24-hours exposure.

Area of study

This study was conducted in Mumbai, the commercial capital located on the west coast of India with a population exceeding 14 million. Andheri, a western suburb of Mumbai, was selected as the area of study, because it contains a representative mix of roads with high traffic density, industrial estates and residential areas typical of the city.

The study was conducted in two phases. In the first phase, the concentration of Respirable Particulate Matter (RPM) was measured with the help of personal samplers at breathing level at following locations selected on the basis of sources:

1. Campus of Sardar Patel College of Engineering: To represent the background air quality.
2. Apana Bazar Traffic Junction, Andheri (West): To represent air pollution due to automobile exhaust and resuspension of dust from roads.
3. Hotel Sea View, Juhu Beach: To represent natural/marine sources.
4. Indoor-Home: To represent indoor residential sources.
5. Personal Exposure: Apart from four locations mentioned above, personal exposure was also monitored for respondents from the study area.

Sardar Patel College of Engineering is located on a 40-acre campus, consisting of playgrounds, a garden, trees, and a small lake. There is no major air pollution source on the campus. Due to these reasons, it was assumed that the campus represents background air quality. The possibility of locating a station at an industrial area was also explored; however, most of the industries are small scale and they are interspersed within residential areas. In one area demarcated for industries, most of the establishments were of commercial nature without any specific air pollution source. Therefore, no location could be set up to represent industrial sources.

In the second phase, personal exposure for the selected respondents was monitored in the study area as described previously.

Selection of air pollutant

RPM, Suspended Particulate Matter (SPM), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2) are the criteria air pollutants routinely monitored by regulatory authorities in India. However, in this study RPM was selected due to its high levels in Mumbai and its adverse impact on health (Zohir, 2004). Sampling for RPM can be done for three sizes: 2.5, 5, and 10 μm. At least one study has found a correlation between concentrations of different particulate sizes (Chow *et al.,* 1999). The SKC personal sampler used in this study has a PM_5 cut point. Apart from being respirable, the comparatively easy availability of PM_5 samplers is also one reason for selecting this particle size. They are widely used in measuring the occupational exposure to RPM all over the world. The respirable dust was digested and analyzed for 12 metals.

Selection of respondents

Two respondents, both employed at Sardar Patel College of Engineering, were monitored for personal exposure to RPM, one each from the low- and middle-income groups. An annual income of less than Rs. 1 lakh (US$ 2280) was considered Low-Income Group (LIG), while between Rs. 1 lakh and Rs. 5 lakh (US$ 11370) was considered Middle-Income Group (MIG). The LIG respondents were residing in a ghetto-type structure. MIG respondents resided in an apartmenttype building. The average commuting time of both these respondents was 40 minutes. The LIG respondent walked to work, and the MIG respondent drove a car.

Sampling time

The sampling time for each respondent was 48 hours, or two consecutive days. A 24-hour sampling period is enough to measure daily integrated exposure, and is a suitable indicator of health risk. However, for better accuracy, 48-hour sampling period was selected to collect more mass and to help in detecting metals, many of which are below detection limits.

Monitoring period

First phase (source location monitoring) monitoring period occurred from March 21 to June 02, 2002. On average, each location was monitored once a week. Monitoring period for second phase (respondent personal exposure monitoring) was for three months from October 23, 2002 to January 23, 2003. Each respondent was monitored once a week on average for 48 hours.

Questionnaire Survey

Each respondent filled in an activity diary and a questionnaire about their surroundings with the help of volunteers. The activity diary consisted of half-hour time bands for the day and 1-hour time periods from midnight to 6 a.m. Individuals had to identify for each time band whether they were indoors at home, work or other, outdoos at home, work or other, or in transit in any form of motor vehicle or public transportation. A questionnaire survey was carried out to collect other data, such as housing characteristics like house size, windows' size and period of their opening, type of fuel used – Kerosene/Liquified Petroleum Gas, duration of use of fuel. Data on socio-economic status, was also collected through questions about type of occupation, family income, number of persons in the family, gender and age of family members. The correlation between this data and the personal exposure is explored later in this paper.

Factor Analysis for Source Apportionment

Factor analysis was used for source apportionment in attempts to identify underlying variables, or factors, that explain the pattern of correlations within a set of observed variables. Factor analysis is often used in data reduction to identify a small number of factors that explain most of the variance observed in a much larger number of manifested variables. SPSS software is used for factor analysis.

Data used for Factor Analysis

A total of 22 samples combined from the two respondents (14 MIG + 8 LIG) were collected. Each sample filter was digested and analyzed for copper, manganese, lead, sodium, chromium, calcium, potassium, zinc, iron, arsenic, cadmium and nickel. The concentration of these metals was used in the factor analysis.

MATERIALS AND METHODS

Sampling and Analysis Method

Personal exposure to RPM was measured by personal sampler (SKC, USA). Polycarbonate membrane filters, 37-mm in diameter with a pore size of 0.8 μm, are used. The filter was kept in an airtight cassette before and after sampling to avoid absorption of moisture. The flow rate was maintained at 1.9 L/min and calibrated before and after sampling with a cyclone loaded with filters. If the flow rate differed by more than 5% after sampling, the observation was considered as void.

Analysis for metals was conducted with an atomic absorption spectrophotometer (GBC 932 B Plus, Australia).

Sampling protocol

The sampling was started at the workplace in the morning of the first day. After duty hours, both the respondents carried the sampler to their residences with the charged pump and the sampling was carried out during the night, either in the living room or the bedroom. The cycle was repeated for the next day. The sampler was not to be kept near a window or stove.

The personal sampler can operate for about 10 to 12 hours, after which its battery needs recharging. In order for respondents to conduct sampling for two whole days (48 hours), the cyclone attached to the pump on the first day was attached to another freshly charged pump, while the first is recharged overnight. The procedure is repeated for the second day and thus 48 hours of sampling is accomplished.

RESULTS AND DISCUSSION

As discussed in the *Study Design* section, air monitoring was carried out in two phases. In Phase I, personal exposure was monitored at selected sites representing different sources, such as traffic, natural, indoor, and background, along with the personal level monitoring. In Phase II, personal exposure to RPM was monitored for two respondents.

Personal Exposure Monitoring at Selected Source Sites (Phase I)

In Phase I, the term personal exposure monitoring is used to indicate that RPM was monitored using personal samplers at selected sites; hence, the sample represents daily personal exposure at the particular site. Personal exposure to respondents was not measured at the selected sites. Phase I monitoring was conducted from March 21 to June 2, 2002. On an average each site was monitored once a week for the 48-hour sampling period. Also personal exposure of a respondent from the study area was monitored once a week. Seven valid readings were obtained for each site and personal exposure. The results are summarized in Table 1.

Table 1. Average RPM concentration at selected sources and personal exposure.

Site/ Personal Exposure	Average RPM concentration in μg/m^3 (n = 7)
Personal Exposure	149.71 ± 83.68
Indoor-Home	125.68 ± 73.16
Traffic Junction	254.37 ± 73.85
Background	150.62 ± 78.58
Sea Shore	111.65 ± 33.73

The Traffic Junction site recorded the maximum, whereas the Sea Shore site recorded the minimum RPM concentration. The Indoor-Home and the Background concentration fell in between. Apparently, the air quality at the Background site is affected by the traffic at the adjoining roads. Hence, the Sea Shore site better represents the background air quality. Personal exposure falls between the Indoor-Home and Traffic Junction air quality. The excess exposure in Indoor-Home may be due to outdoor sources, such as traffic entering through doors and windows. The Indian NAAQS for RPM (PM_{10}) is 100 μg/m^3. This level is exceeded at all sites and for personal exposure.

Table 2 shows results obtained from respirable dust samples collected at the source stations that were digested and analyzed for metals by the atomic absorption spectrophotometer. The results show some interesting trends. For example, lead is supposed to be the tracer element for traffic; however, for the last five years, only unleaded gas has been used throughout India, so the traffic site is not associated with high levels of lead. Apart from Na and Zn, the concentration of all other metals at Sea Shore site is lower than that of the Background site. Thus metal analysis results of PM_5 concentrations confirm that the Sea Shore site better represents background air quality.

Manganese was rarely detected at any of the sites. Although cadmium was detected at all the sites, the concentration was very low and there was not much difference in the concentration to credit the cadmium concentration to one particular type of source. The concentration of chromium was also almost the same at every site, but what is significant was the absence of chromium from the Sea Shore site. This indicates that chromium contribution may be solely due to anthropogenic sources. The concentration of copper was the highest at Traffic Junction, which may indicate auto-exhaust origins. The concentration of iron was the same almost everywhere, but it was also found that in a couple of homes the concentration was very high. The concentration of sodium was almost the same everywhere, but was slightly greater at the Sea Shore site confirming the expectation that sodium is of marine origin. The concentration of lead was almost the same at almost all the sites, but was significantly low at the marine front, underlining its anthropogenic origin.

Table 2. Average concentration (Mean ± Std. Dev.) of metals at selected source sites and personal exposure in $\mu g/m^3$.

Site/Personal Exposure	Mn	Cd	Cr	Cu	Fe	Na	Pb	Zn
Traffic Junction	0.6213**(1)**	0.0033 ± 0.0020**(3)**	1.4299 ± 1.6352**(3)**	0.1355 ± 0.0717**(3)**	5.9302 ± 7.8116**(7)**	1.4418 ± 0.8892**(5)**	0.5025 ± 0.3264**(5)**	0.2723 ± 0.1669**(5)**
Background	Not detected	0.0114 ± 0.0079**(4)**	1.5476 ± 1.1775**(4)**	0.0441 ± 0.0184**(3)**	4.5804 ± 6.2993**(7)**	1.3870 ± 0.5247**(5)**	0.9000 ± 0.1102**(4)**	0.1484 ± 0.0846**(4)**
Personal Exposure	0.0091**(1)**	0.0061 ± 0.0026**(3)**	2.5310**(1)**	0.1256 ± 0.0356**(2)**	2.6315 ± 1.4224**(7)**	1.0979 ± 0.8825**(3)**	1.0576 ± 0.4749**(2)**	0.1507 ± 0.1551**(2)**
Indoor-Home	0.0462**(1)**	0.0045 ± 0**(3)**	1.7177 ± 0.0323**(2)**	0.0525 ± 0.0355**(2)**	10.8707 ± 11.5185**(5)**	1.5652 ± 1.1452**(6)**	0.5013 ± 0.2906**(4)**	0.1850 ± 0.1551**(4)**
Sea Shore	0.0785**(1)**	0.0069 ± 0.0046**(4)**	Not detected	0.0319**(1)**	4.8055 ± 5.1964**(6)**	1.5983 ± 1.3759**(7)**	0.2033 ± 0.2681**(2)**	0.2786 ± 0.3747**(2)**

Note: The figures in the parenthesis represent the number of detected samples out of seven.

Amongst the metals, the Indian NAAQ standard is set only for lead, which is 1.0 $\mu g/m^3$. In this study, personal exposure to lead (1.0576 $\mu g/m^3$) slightly exceeded the standard. At the other sites, the concentration of lead conformed to standard. The higher personal exposure to lead compared to other sites needs to be investigated.

Personal Exposure Monitoring of Selected Respondents (Phase II)

As discussed, personal exposure to RPM (PM_5) was monitored for two respondents working in the same organization—one from a middle- and one from a lower-income group. As the questionnaire survey revealed, their housing characteristics were different. The MIG respondent was living in an apartment-like building where the ventilation was better, and where low-pressure gas (LPG) was used as cooking fuel. The LIG respondent was residing in a chawl, or slum-like, congested locality where ventilation was relatively poor and where kerosene and other low-grade fuels were used for cooking, along with LPG. Tables 3 and 4 show the personal exposure to RPM for MIG and LIG respondents, respectively.

In the sample column, M and L represent the sample corresponding to the MIG and LIG respondent, respectively. The subsequent numbers show date, day, and month of sampling. For example, 23_10 means the sampling was carried out on October 23, 2002. Similarly, 22_1 means the sampling was carried out on January 22, 2003. Due to vacation, only one sample was collected in November. In the sampling period from October 23, 2002 to January 23, 2003 a total of 22 samples were collected. Out of these, 14 and 8 were from MIG and LIG respondents, respectively. Results and conclusions should be viewed with the perspective that only one respondent each from middle- and low-income groups was monitored in this study. This was due limitations in manpower and other resources.

The average personal exposure to RPM (PM_5) was 110.91 µg/m^3 (n = 22). This exceeds the Indian NAAQS (PM_{10}) of 100 µg/m^3 by a factor of 1.11. If PM_5 concentration is converted to corresponding PM_{10} concentration, this factor will increase further. However, in the case of the MIG respondent, the average RPM (PM_5) exposure was 73.11 µg/m^3 (n = 14). For the LIG respondent, it was 240.17 µg/m^3 (n = 8), suggesting exposure to higher doses of air pollutants probably due to poor residential microenvironment. Results in Table 5 show metal concentrations that were detected. Nickel (Ni) and Cadmium (Cd) could not be detected.

Table 3. Personal exposure to RPM for MIG respondent.

Sr. No.	Sample	Concentration in µg/m^3
1	M23_10	182.55
2	M30_10	76.83
3	M29_11	90.79
4	M9_12	48.51
5	M12_12	36.12
6	M16_12	35.12
7	M19_12	85.66
8	M23_12	104.51
9	M31_12	49.46
10	M6_1	77.95
11	M8_1	60.00
12	M14_1	40.44
13	M20_1	91.53
14	M22_1	44.06
	Average (n = 14)	73.11
	Standard Deviation	39.09

Table 4. Personal exposure to RPM for LIG respondent.

Sr. No.	Sample	Concentration in µg/m^3
1	L23_10	80.87
2	L28_10	309.94
3	L2_12	615.82
4	L10_12	279.21
5	L19_12	128.82
6	L24_12	49.30
7	L6_1	321.71
8	L20_1	135.72
	Average (n = 8)	240.17
	Standard Deviation	184.88

Table 5. Personal exposure to metals in the Respirable Particulate Matter in µg/m^3.

Element	MIG Respondent (n =14)		LIG Respondent (n = 8)		Combined (n = 22)	
	Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.
Cu	0.701	0.51	0.738	0.21	0.727	0.59
Mn	4.694	2.90	4.141	1.94	4.450	3.05
Pb	0.234	0.33	0.204	0.24	0.284	0.33
Na	107.057	46.82	116.19	8.91	106.90	41.69
Cr	26.339	10.26	27.109	4.03	27.631	8.80
Ca	86.547	32.86	72.74	19.15	83.96	35.39
K	17.360	5.42	20.632	6.68	17.843	5.36
Zn	4.647	0.99	5.126	0.34	5.017	1.25
Fe	43.560	27.71	38.975	20.44	41.979	30.26
As	5.217	6.64	17.976	15.65	7.695	9.06

Human Exposure to Toxic Metals

Metals like Pb, Ni, Cr, Cd, As are considered toxic. The level of average personal exposure to lead was 0.284 µg/m^3 (n-22), which is below the standard of 1 µg/m^3. Concentrations of chromium and arsenic were appreciable; however, there are no Indian NAAQ standards for these metals. There was no appreciable difference in the average personal exposure of most of the metals for MIG and LIG respondents. However, average personal exposure to arsenic for LIG respondent is 3.4 times more than that of MIG respondent.

Factor Analysis

As discussed in the study design, factor analysis attempts to identify underlying variables, or factors, that explain the pattern of correlations within a set of observed variables. In the present study, the concentration of 10 detected metals for each of the 14 and 8 samples constitutes the database for factor analysis. Data for MIG and LIG respondents were analyzed separately to identify factors specific to the respective population subgroup. Factors represent the group of metals associated with a particular source.

Steps in Factor Analysis

Factor analysis consists of three main steps:

1. The correlation matrix is computed. If the variable has very small correlations with others, you may consider eliminating it from the list of variables, as it is not significant.
2. The factor loadings are estimated. Here principal component analysis is used as a method for factor extraction.
3. The loadings are rotated to make them more interpretable. Rotation methods make the loading of each factor either large or small, not in between. Here, Varimax rotation is used.

Factor analysis on the MIG respondent samples resulted in two components as shown in Table 6. The two sources brought out by the rotated component matrix are: Source 1, Fe, Mn, Cu, Cr; Source 2, As, Na, Pb. Source 1 represents anthropogenic sources, such as traffic and industry; whereas, Source 2 represents natural sources, such as marine, crustal and road dust.

Table 6. Rotated Component Matrix for samples of MIG respondent.

	Component	
	1	2
Cu	0.902	0.264
Mn	0.906	0.205
Pb	0.292	0.736
Na	0.301	0.874
Cr	0.836	0.374
Ca	0.606	-0.573
K	0.704	0.539
Zn	0.505	0.532
Fe	0.923	0.155
As	0.139	0.932

In the case of LIG respondent, the first two sources are same as in the case of MIG respondents. However, there is the additional third source which may be linked to poor ventilation and the use of low-grade cooking fuels in the residential environment of the LIG respondent. A study

(Kulkarni, 2003) has linked the presence of potassium to the indoor residential microenvironment, which in turn influences personal exposure.

Factor analysis on the LIG respondent samples resulting in three components is shown in Table 7.

Source 1: Fe, Mn, Cu, Cr

Source 2: Pb, Na

Source 3: K, Zn

Table 7. Rotated Component Matrix for samples of LIG respondent.

	Component		
	1	2	3
Cu	0.941	0.304	
Mn	0.982	0.157	
Pb		0.939	
Na	0.302	0.826	0.410
Cr	0.761	0.410	0.458
Ca	-0.245	-0.590	-0.207
K	0.201	0.205	0.862
Zn	-0.339	0.327	0.83
Fe	0.992		
As	-0.588	0.487	-0.617

CONCLUSIONS

1. Air monitoring at the selected source sites revealed that RPM (PM_5) concentration is high and exceeds the Indian NAAQ PM_{10} standard of 100 $\mu g/m^3$ at all sites. The Sea Shore site better represented background air quality. The Background site originally selected was apparently affected by anthropogenic sources to some extent.
2. Metals concentrations were lower at the Sea Shore site. Analysis of metal concentrations in the respirable dust provided some guidelines for source apportionment. Lead was not associated with the Traffic site. Manganese, chromium, copper, and iron were linked with anthropogenic sources, such as traffic. Sodium was associated with marine source. Zinc can be associated with traffic, as well as well as Indoor-Home site.
3. Average personal exposure to RPM of MIG and LIG respondents were 73.11 $\mu g/m^3$ (n = 14) and 240.17 $\mu g/m^3$ (n = 8), respectively. The latter exceeds the Indian NAAQ standard for PM_{10}. The higher personal exposure of LIG respondent may be linked with the indoor residential environment which is characterized by poor ventilation and use of low-grade cooking fuel. Respirable dust was analyzed for 12 metals, namely Cu, Mn, Pb, Na, Cr, Ca, K, Zn, Fe, As, Ni and Cd. Out of these, Nickel (Ni) and Cadmium (Cd) could not be

detected. The levels of average Personal Exposure to lead for MIG and LIG respondent were 0.23 μg/m^3 (n = 14) and 0.20 μg/m^3 (n = 8), respectively, which are below the standard of 1 μg/m^3.

4. Factor analysis for samples of MIG respondent separately brings out two principal sources. Source 1 corresponds to a group of metals of anthropogenic origin, such as traffic and industry. Source 2 corresponds to a group of metals from natural sources, such as marine, crustal, and road dust. Factor analysis for samples of LIG respondent separately brings out three principal sources. Source 1 and 2 are the same as in the case of MIG respondent. However, there is an additional third source which corresponds to the residential environment of the LIG respondent. This source may be traced to burning of low-grade cooking fuel.
5. The air pollution due to anthropogenic sources, such as traffic and industry is the major source contributing to the personal exposure to respirable particulates. Therefore, efforts should be made to reduce air pollution due to these sources. In India, there are many old vehicles (more than 15 years old) still running on the road. These should be gradually phased out and public transportation systems should be improved to reduce idling time of vehicles at traffic signals. Many existing unauthorized small-scale industries should be identified and brought under the purview of the regulatory authorities. Efforts should be made to spread the use of higher-quality fuels, such as LPG, in low-income group localities. Use of low-grade cooking fuel, such as kerosene, and biofuels, such as wood, should be discouraged. Awareness about necessity of good ventilation should be increased.

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