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# Source Identification of Different Size Fraction of $PM_{10}$ Using Factor Analysis at Residential cum Commercial Area of Nagpur City

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**Abstract** Particulate size distribution of $PM_{10}$ and associated trace metal concentrations has been carried out in residential cum commercial area of Mahal at Nagpur city. Sampling for size fraction of particulate matter was performed during winter season using eight-stage cascade impactor with a pre-separator and toxic metals were analyzed using inductively coupled plasma-optical emission spectroscopy (ICP-OES). The average concentration of $PM_{10}$ and fine particulate matter (effective cut of aerodynamic diameter $\leq$2.2 μm) was found to be 300 and 136.7 μg/m$^3$, respectively which was exceeding limit of Central Pollution Control Board. Maximum mass concentration of 41 μg/m$^3$ in size range of 9.0–10.0 μm and minimum mass concentration of 19 μg/m$^3$ in size range 2.2–3.3 μm was observed. Metals (Sr, Ni and Zn) were found to large proportions in below 0.7 μm particle size and could therefore pass directly into the alveoli region of human respiratory system. Factor analysis results indicated combustion and vehicular emission as the dominant source in fine mode and resuspended dust was dominant in medium mode while crustal along with vehicular source was major in coarse mode of particulate matter.

**Keywords** Size distribution · Metals, PCA

Size distribution of atmospheric particles with trace metals are found more important since this not only influences the toxicity of a metals when inhaled but also controls the extent to which metals may be dispersed via atmospheric transport. The distribution of trace metals within atmospheric particles in all over world has been studied from nineteenth century at Europe (Horvath et al. 1996), United Kingdom (Allen et al. 2001), Poland (Krzemińska-Flowers et al. 2006), Pittsburg, USA (Cabada et al. 2004). In Indian context, size distribution of atmospheric aerosols and its chemical composition was reported by Mishra (1988) in Mumbai city. Similar study was also conducted at Agra using an eight stage Anderson cascade impactor (Kulshrestha et al. 1998). Some more important studies were carried out by Gokhale and Patil (2004) in Mumbai and Yadav and Rajamani (2006), in the region of N-NW, India.

Various studies for metals emitting sources in ambient air, e.g. fossil fuel combustion contributes to Al, Fe, Ca, Mg, K, Na, As, Pb, Cd, Sc and Hg (Furimsky 2000), Pb and Zn to wood combustion (Mohn et al. 2002), vehicular traffic to Cd, Cr, Cu, Ni, Pb, Zn (Westerlund 2001) and metal alloy industries to Cd, Cr, Al, Fe, Ni, Zn, Pb, Cu etc. (Harrison 1986) were reported. Recently, source apportionment of size-resolved ambient particles using various techniques (PMF, PCA etc.) was studied in various countries (Han et al. 2006; Gietl and Klemm 2009). In India, studies on source apportionment of various size fraction of $PM_{10}$ were reported by Sharma and Patil (1992) for Mumbai and Balchandran et al. (2000), Shrivastava and Jain (2007) and Chelani et al. (2010) for Delhi city. However, source apportionments on size distribution of $PM_{10}$ and associated metal in Nagpur city have not been yet reported.

In view of this, present study focused on the source apportionment of different particle size fraction of $PM_{10}$ for residential cum commercial site of Nagpur city. The varimax rotated factor analysis technique based on the principal components has been applied on the elemental

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composition of various sizes of $PM_{10}$ used in the determination of the various sources.

## Materials and Methods

Distribution of size fraction of PM10 was carried at sampling location in Mahal which is residential cum commercial area of Nagpur city. The sampling location is shown in Fig. 1. Site location represents densely populated and congested area with narrow roads having high traffic density of two/four wheeler vehicles, commercial activities which includes gold smelting shops, cloth markets, grocery shops, bakeries and many more shops which results in increasing traffic and crowd. Diesel generator (DG) sets were also used during power shortage in market areas.

Sampling was performed using Anderson non-viable eight-stage cascade impactor (model no. 20–800, Thermo Electron Corporation, Franklin, USA) with a pre-separator and back-up filter. Sampler was placed in one of the roof terrace of residential house, 3 m above the ground level. Sampling was performed over a 24 h period starting at 8:00 AM.

The sampler was operated at a flow rate of 28 L $min^{-1}$ and having 50% cut-off aerodynamic diameters of <10, 9, 5.8, 4.7, 3.3, 2.1, 1.1, 0.7, and collects all particles smaller than 0.4 μm on an after-filter. The initial and final flow rate was checked by dry gas meter (Model 12393959, Invensys (TM) supplied by Thermo Fisher Scientific) and flow rate was found to be within ±1% L $min^{-1}$. Particles were collected on glass microfibre filters (Whatman, GF/A, USA).

After sampling, filters were conditioned for 24 h at room temperature 25°C and 45% humidity. Mass was determined for different fractions gravimetrically using Mettler AE 163 with 0.00001 g readability. The particle concentration was then determined for each size range and for $PM_{10}$ by the addition of mass concentration of each fraction stage of the impactor. Each filter was weighed at least three times and readings were accepted when the difference was not exceeding above 5 μg. Blank filters (laboratory and field) were weighed before and after real samples to correct the mass of the exposed filters for particulate matter (PM) during handling.

To determine metal concentration in size segregated PM, the filters were digested with microwave digestion chamber (ETHOS 900, make-milestone, Italy) for 20 min using 10 mL 12 N concentrated $HNO_3$ (Merck, CAS 7697-37-2) in Teflon vessel. Digested sample was then filtered after cooling through Whatman 41 filters (Ashless filter papers 125 mm, cat no. 1442 125) into properly cleaned volumetric flask. Similarly, field and laboratory blanks were prepared. Calibration standards were prepared in the range of 25–500 ng/L through serial dilution of standard stock solution of multi-element having concentration of 1,000 mg/L (Merck, cat no. 1.11355.0100). The analysis was performed by inductively coupled plasma-optical emission spectroscopy (Perkin Elmer, USA). Limit of detection was determined for As, Ba, Cu, Mg, Fe, Mo, Ni, Pb, Si, Sr and Zn as 0.085, 0.028, 0.0078,0.006,

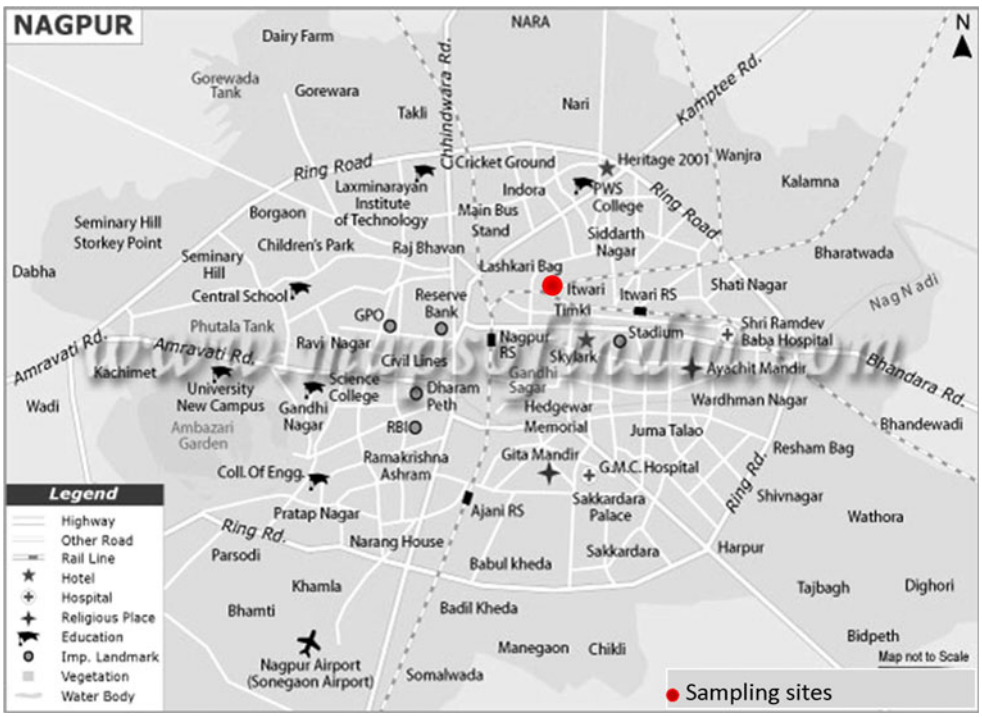


**Fig. 1** Location of sampling sites

0.017,0.016, 0.010, 0.0045, 0.025, 0.073 and 0.0355 μg/m$^3$, respectively. Samples were analyzed by spiking with a known amount of metals concentration to calculate recovery efficiencies. The recoveries of metallic elements were 88.2%, 85.2%, 80.4%, 86.5%, 88.6%, 87.4%, 88.9%, 87.5%, 94.5%, 91.3% and 92.6% for As, Ba, Cu, Mg, Fe, Mo, Ni, Pb, Si, Sr and Zn, respectively. The range of recovery efficiency varies between 80.4% and 94.5%.

## Results and Discussion

The airborne particulate of each size fractions 0.0–0.4 up to 10.0 μm were collected. The average $PM_{10}$ concentration and average fine particulate matter (effective cut of aerodynamic diameter ≤2.2 μm) concentration was found to be 300 and 136.7 μg/m$^3$, respectively. It reveals that the total 24 hourly average of $PM_{10}$ concentration and average concentration of fine particulate matter violating the CPCB limit of 100 and 60 μg/m$^3$, respectively. The higher concentration of PM may be contributed due to the conjunction in traffic, highly commercial activities and old and high rising building prevents dispersion of particulate matter. Figure 2 shows particle size distribution of each size fraction. The result indicates that highest mass concentration as 41 μg/m$^3$ in size range of 9.0–10.0 μm and minimum percent mass concentration of 19 μg/m$^3$ in size range 2.2–3.3 μm was observed. In size fraction of 0.7–1.1 μm mass concentration was 31 μg/m$^3$ and in fine size range of 0–0.4 μm and 0.4–0.7 μm, percent mass concentration 28 and 23 μg/m$^3$ were observed.

As per the classification of ISO-7708 (ISO 1995) fine particle size below 1.1 μm corresponds to the alveolar fraction deposited in the lung alveoli. The medium (1.1–4.7 μm) and coarse range (4.7–10 μm) corresponds to the tracheobronchial and nasopharyngeal fractions, respectively. According to these classifications, percent mass distribution of $PM_{10}$ is shown in Fig. 3. The result indicate that percentage mass concentrations in the coarse region was around 37% and in fine mode, it was about 34% and 28% of mass concentration with medium mode.

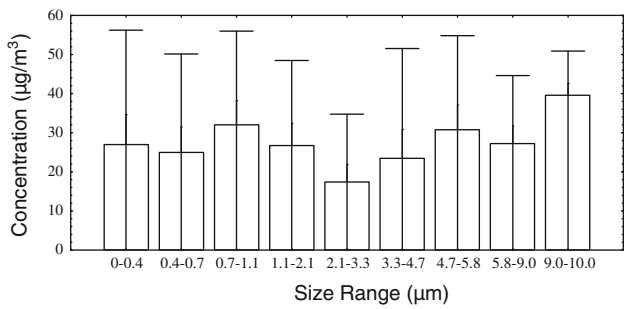


**Fig. 2** Concentration of each size fraction of $PM_{10}$

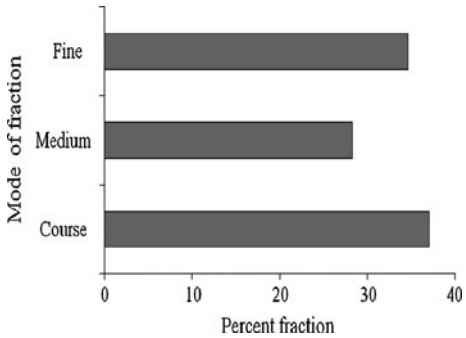


**Fig. 3** Percent distribution of mass coarse, fine and medium of $PM_{10}$

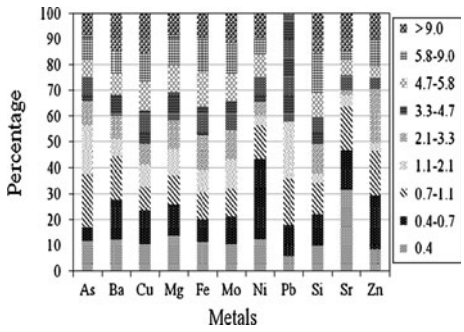


**Fig. 4** Percent distribution of individual metals in $PM_{10}$

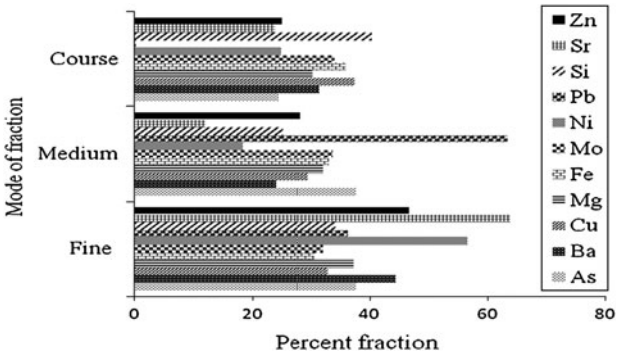


**Fig. 5** Percent distribution of metals in coarse, fine and medium mode of $PM_{10}$

The relative trace metals contributions of each size fraction are illustrated in Fig. 4. The result indicate that among all metals, maximum contribution of Sr (32%) and Mg (14%) were found in the below 0.4 μm. Ni (31%) and Zn (21%) were found maximum in the particle size range 0.4–0.7 μm while, As (21%) and Ba (17%) were maximum in the size range 0.7–1.1 μm. The remaining metals like Fe, Pb, Si and Cu were observed maximum in size range of 2.1–3.3 μm, 3.3–4.7 μm, 5.8–9.0 μm and 9.0–10 μm, respectively. There was no significant variation for Mo (11–12%) in all size fractions. Similar to classification of $PM_{10}$, distributions of different metal in fine, medium and coarse mode are shown in Fig. 5. The results show that Zn

**Table 1** Factor analysis of different size fraction of $PM_{10}$

| Metals | Coarse | | | Medium | | | Fine | | |
|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F1 | F2 | F3 | F1 | F2 | F3 |
| As | – | – | 0.77 | – | – | – | – | – | – |
| Ba | 0.57 | | – | – | – | 0.82 | – | – | 0.72 |
| Cu | – | 0.83 | – | 0.71 | – | 0.52 | 0.77 | – | – |
| Fe | – | – | – | 0.63 | – | – | – | 0.77 | – |
| Mg | – | – | – | 0.92 | – | – | – | 0.72 | – |
| Mo | 0.63 | – | 0.70 | – | – | – | – | – | – |
| Ni | 0.90 | – | – | 0.66 | – | – | 0.94 | – | – |
| Pb | 0.93 | – | – | – | 0.5 | 0.74 | – | – | 0.77 |
| Si | – | 0.88 | – | – | 0.56 | – | – | – | 0.65 |
| Sr | 0.87 | – | – | 0.92 | – | – | – | – | – |
| Zn | 0.75 | – | – | – | – | 0.64 | 0.93 | – | – |
| % variance | 44.8 | 25.0 | 13.2 | 39.6 | 20.3 | 14.5 | 29.4 | 24.8 | 17.0 |
| Possible source | VE + Cru | RD | CB + Smelt | RD + CB | VE + RD | RB + CB | VE + CB | RD | VE + Crus |

*VE* vehicular exhaust, *RD* resuspension of road dust, *RB* refuse burning, *CB* combustion, *Cru* crustal, *Smelt* smelting

(45%), Sr (65%) and Ni (55%) contribute maximum and other metals varied from 30–45% in fine mode. However, percent contribution of Si (40.3%) and Pb (63.3%) was maximum in coarse mode and in medium mode, respectively.

We have tried to identify and estimate the possible sources of different size fractions using principle component analysis (PCA). PCA was executed by the Varimax Rotated Factor Matrix method, based on orthogonal rotation criterion which maximizes the variance of the squared elements in the column of a factor matrix having eigen values >1, using a statistical package Stastica (5.0). It produces factors that have high correlations with one smaller set of variables and little or no correlation with another set of variables (Stevens 1996). The varimax rotated factor loadings was computed for coarse (4.7–10 μm), medium (1.1–4.7 μm) and fine mode (<1.1 μm) and given in Table 1. In coarse mode, three factors together accounted for 83.08% of the total variance. The high loadings for Ba, Ni, Mo, Pb, Sr and Zn in the first factor indicated the significance of crustal and vehicular emission. The second factor correlated with Cu and Si indicating resuspension of dust, whereas the third factor was correlated with combustion and smelting. In medium mode, three factors together accounted for 74.4% of the total variance. The first factor which has high loadings for resuspension of road dust and some combustion sources accounted for 39.6% of total variance. Vehicular emission dominated at factor 2, whereas contribution from refuse burning and combustion was significant in factor 3.

In the fine mode, three factors together accounted for 71.26% of the total variance. The high loadings for Cu, Ni and Zn showed the dominance of combustion source. The high correlation of factor 2 with Fe and Mg attributed to resuspension dust while factor 3 correlated well with Ba, Pb and Si mainly due to vehicular and crustal sources. The findings compared well with the other studies e.g. by Shrivastava and Jain (2007), where two sources were identified (crustal re-suspension and building material) of TSPM and PM10.9, while three sources (crustal re-suspension, building material and vehicular) and four sources (crustal resuspension, industrial, thermal power plants and vehicular) for PM1.6 and PM0.7, respectively for areas of Delhi. In another study at Delhi by Balchandran et al. (2000), three major sources for fine and coarse fraction of $PM_{10}$ were identified namely vehicular emission, industrial emissions and soil resuspension.

The findings of the study indicated that the concentrations of metals (As, Zn, Ba, Ni, Sr and Si) show invariably significant distribution with respect to size fractions of $PM_{10}$. However, Metals (Mo, Fe, Mg and Cu) has no much variation in distributions among all size fractions. It can be seen that the metals Sr (47%), Ni (43%), and Zn (30%) were found large proportions below 0.7 μm size and could therefore pass directly into the alveoli. As trace metals are more harmful for human health, it is necessary to find out the sources and hence factor analysis suggests that the vehicular, resuspension of dust and combustion are the major source contributing towards the particulate emission. Hence, present study indicates a need for appropriate urban traffic planning and management to prevent elevated level of fine PM concentration as well as trace metal concentration on the various receptors and thus safeguard public health from ill-effects of fine particulate matter and toxic metals.

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