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Source apportionment of particulate matter in the ambient air of Hyderabad city, India

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ABSTRACT

Source apportionment of particulate matter (PM) has been carried out for the city of Hyderabad using the chemical mass balance model (CMB8, Ver. 8.0) in PM10 and PM2.5 size modes. Urban particles were collected using Continuous Particulate Matter Analyzer (TEOM) during different seasons conducted in Punjagutta site, a critical traffic corridor, during June 2004–May 2005. The measurement of PM10 & PM2.5 at the site is measured throughout the day. Samples were collected in every 15 min; additionally instrument computes the total mass accumulation for every 30 min, 1-h, 8-h and 24 h average mass concentrations. Chemical characterization of PM10 & PM2.5 was done by ICP-MS. Source apportionment studies were carried out to quantify the possible sources affecting region using CMB Model Ver. 8.o. The CMB8 executed separately for both coarse and fine sizes. Results obtained by CMB indicate the dominance of resuspended dust (40%), followed by vehicular pollution (22%), combustion (12%), industrial (9%) and refuse burning (7%) in PM10; while in PM2.5 vehicular pollution (31%) dominated over resuspended dust (26%), combustion (9%), industrial (7%) and refuse burning (6%).

1. Introduction

Due to rapid industrialization, urbanization and increasing population alarmingly polluting the basic resources required to sustain life. The swift pace of industrial and economic activities in many developing countries contributed significantly to an increased level of airborne particulate matter, enriched in many toxic heavy metals. Among the variety of factors influencing health of an individual, natural elements and manmade environmental modifications play crucial role. Chemical agents that are released into the environment from various anthropogenic activities impact human health seriously. The respiratory system is one major route whereby these chemicals and toxic agents enter the body and causing disorders, including mortality (WHO Report, 2002). Any action or strategy to preserve the delicately balanced ecological system is in the interest of whole mankind. Public interest in ecology implies the concern for air and water quality and is in increase in demand on limited natural resources in the context of increasing population. When assessing the primary sources that are necessary to sustain life, component air is considered as the most critical resource. If the air becomes polluted, the only alternative to sustain life for each individual is to wear some sort of life support system, which is clearly an unworkable and economically unfeasible. When emissions and unfavorable climatic conditions interact to create undesirable air quality, the atmospheric air pollution is considered to be one of the most dangerous and common type of environmental pollution. Air pollution is assuming global magnitude and its frontiers are no more confined to any particular region of our planet. Automobiles constitute a major part of pollution throughout the world. As global demand for transportation rises, the levels of air pollution

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caused by automobiles has increased dramatically over the past decades. In a city like Mumbai (India) it has been estimated that about 60% of air pollution is caused by automobiles, about 30% by industries and the rest by domestic heating and other operations (Gummeneni, 2008). The incidence of respiratory diseases in most of the major cities in India has also increased considerably over the years. In a study of 2031 children and adults in five major cities of India, of the 1852 children tested, 51.4% had levels of lead in their blood above to 10 μg/dl. The percentage of children with 10 μg/dl or higher lead levels ranged from 39.9% in Bangalore to 61.8% in Mumbai. Among the adults, 40.2% had levels of lead close to 10 μg/dl (The George Foundation Report, 1999).

High concentrations of fine particulate matter represent main air quality problem in Hyderabad, and in order to develop effective control strategies it is necessary to estimate the contributions of different sources to the ambient air quality (Anjaneyulu et al., 2005). Particles larger than about 10 μm are deposited exclusively in the nose and throat, whereas particles smaller than 1 μm are able to reach the lower regions of the lungs. The intermediate size range gets deposited in between these two extremes of the respiratory tract. A statistically significant association has been found between adverse health effects and ambient PM10 concentrations, and recent studies using PM2.5 data have shown an even stronger association between health outcomes and particles in this size range (Ken Gwilliam et al., 2004). Populations at risk from inhaled particles are those most susceptible to pulmonary and heart diseases, infants and elderly people. A 1997 joint study of the World Health Organization (WHO), the World Resources Institute (WRI) and the US Environmental Protection Agency (EPA) estimated that nearly 700,000 deaths worldwide are related to air pollution and that this number can escalate to 8 million deaths by 2020 (Working Group, 1997). Occurrences of respiratory diseases in South Asia resulting from air pollution both indoors and outdoors is estimated to be quite substantial. In each of the 23 cities with a million plus population in India, air pollution levels exceed WHO standards. It has been estimated that in India alone about 500,000 premature deaths are caused by indoor pollution, for mothers and their children who are under 5 years of age (Smith, 2000). Serious respiratory disease related problems have been identified for both indoor and outdoor pollution in Indian cities like Kolkata, Delhi, Lucknow, Mumbai, Ahmedabad, and in several other countries in East Asia including China, Thailand and Korea. There is still inadequate knowledge of the relative effectiveness of sub micron particles compared with larger particles, or the specific roles of black carbon and organic carbon. Such studies need to be performed in the future (UNEP and C4 Report, 2002).

One of the most popular tools currently used to quantify source contributions to airborne particulate matter is the chemical mass balance (CMB) model. The CMB model identifies source contributions to primary particulate matter at specific receptor sites where PM composition measurements are available. This simple model is applied since it has a low computation burden and it does not require information about meteorological conditions or emissions inventories. CMB calculations have been carried out in numerous studies around the world (Abu-Allaban et al., 2002; Chen et al., 2001; Chow et al., 1992; Park et al., 2001; Watson et al., 2001; Zheng et al., 2002). Most of the time, levels of particulate matter exceed air quality standards specified by the Central Pollution Control Board (CPCB), India. In spite of their high levels, data on aerosol composition and their sources specially for PM2.5 is limited for Indian cities, since only few studies on PM2.5 and PM10 were conducted (Khare and Baruah, 2010; Basha et al., 2010; Verma et al., 2010.

2. Materials and methodology

2.1. Study area – Hyderabad – an emerging metropolitan

The present study area Hyderabad is the capital city of the Indian state of Andhra Pradesh. The city lies between the North latitudes 17° 19′ and 17° 30′ N and East longitudes 78° 23′ and 78° 30′ E. Hyderabad city is a part of hitherto considered stable Deccan Plateau formed by the crystalline rocks. The rate of urbanization in Hyderabad city has been very rapid since 1960. The population of Hyderabad has increased from 0.448 million in 1901 to 1.429 million in 1961 and between 1981 and 1991 the population went up to 4.34 million and the rate of the growth so far is 67.04%. According to 2001 census Hyderabad is one of the largest metropolis of India with a population of 55, 33,650 and is projected for about 1, 36, 42,950 by 2020. As the city has grown up rapidly over the years, the quality of environment has declined steadily.

In Hyderabad, one of the major cities in India it is a common sight that traffic police and 2-wheeler riders are wearing gas masks to protect themselves from continuous exposure to harmful pollutants. With the increase in population automobile density has also increased tremendously resulting in heavy automobile pollution. About 18 years ago, the air quality in Hyderabad was good in the light of US standard, unrestrained industrialization in certain sectors and a large increase in traffic have both contributed significantly to the deterioration of air quality over the city, making assessment of air quality in selected areas necessary. Comprehensive information on land use/land cover is the basic prerequisite evaluation of land resources, assessment and utilization & management. Today, with increasing population pressure on land and the resulting changes in the land use pattern and processes, a considerable degree of land transformation and environmental deterioration (air, water & soil pollution) is being witnessed. Therefore it is important to understand the cause and effect of the changes through scientific studies. The location map of the study area is shown in Fig. 1 and the Land Use/Land Cover 2002 year map of Hyderabad City is shown in Fig. 2.

2.2. Urban sprawl of Hyderabad

The concept of urban sprawl, though in simple terms, refers to the areal expansion of urban concentrations, it refers more to the pace and magnitude of land conversion to urban use and areal expansion of the city Fig. 3. In recent times the 'the land needs and areal expansion of cities have increased greatly (Northam, 1975). As the cities expand in area with more population growth the land use gets changed with the hitherto non-urban areas like agricultural lands, other vegetative areas, water bodies etc., getting replaced by concrete structures and black-topped roads (Strahler, 1975). Urban sprawl makes

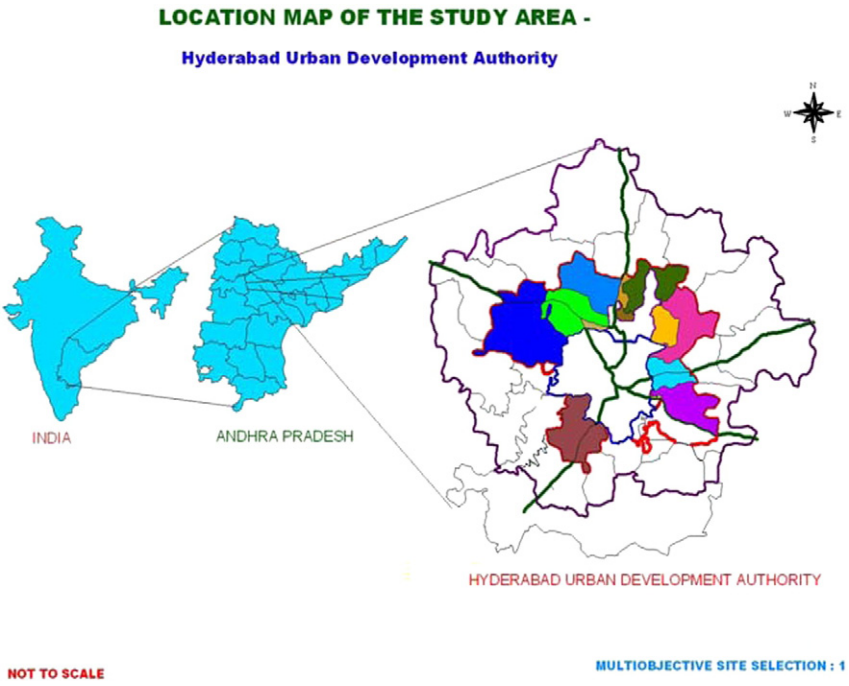

Fig. 1. Hyderabad metropolitan area and environs.
Source: NRSA, Hyderabad.

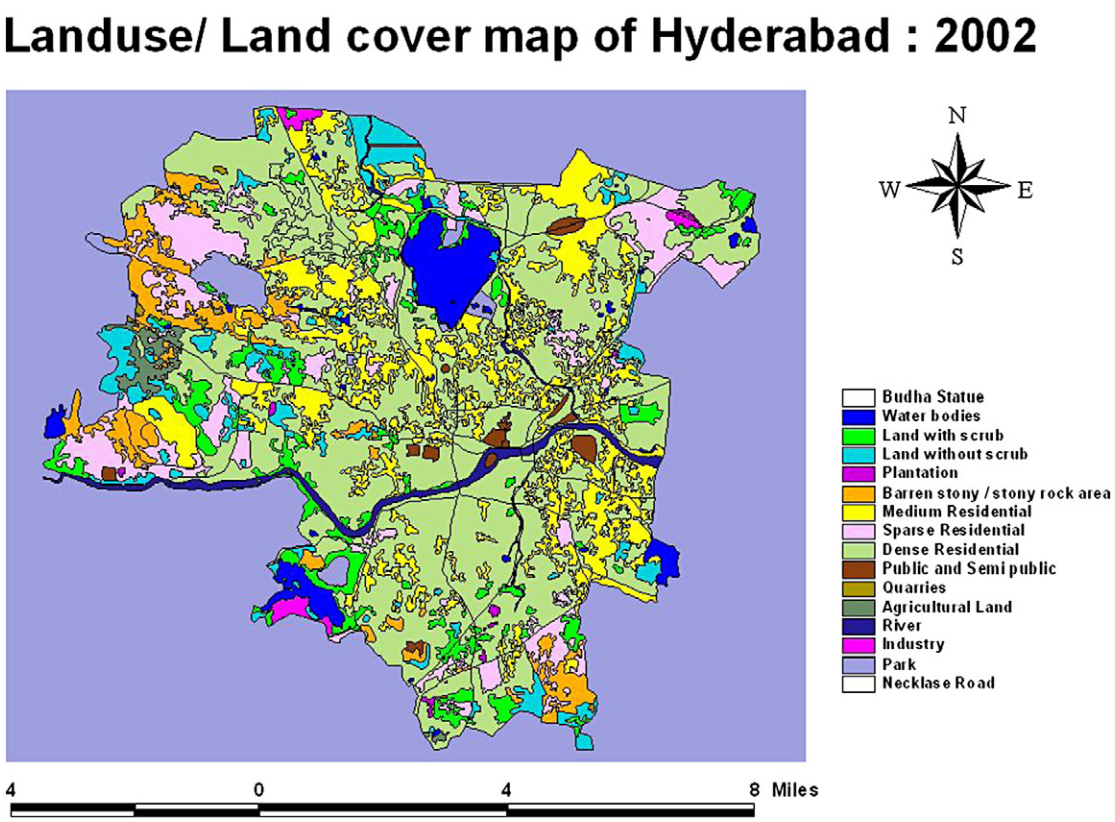

Fig. 2. Land use/land cover map of Hyderabad city.
Source: Centre for Environment, J.N.T UNIVERSITY, Hyderabad.

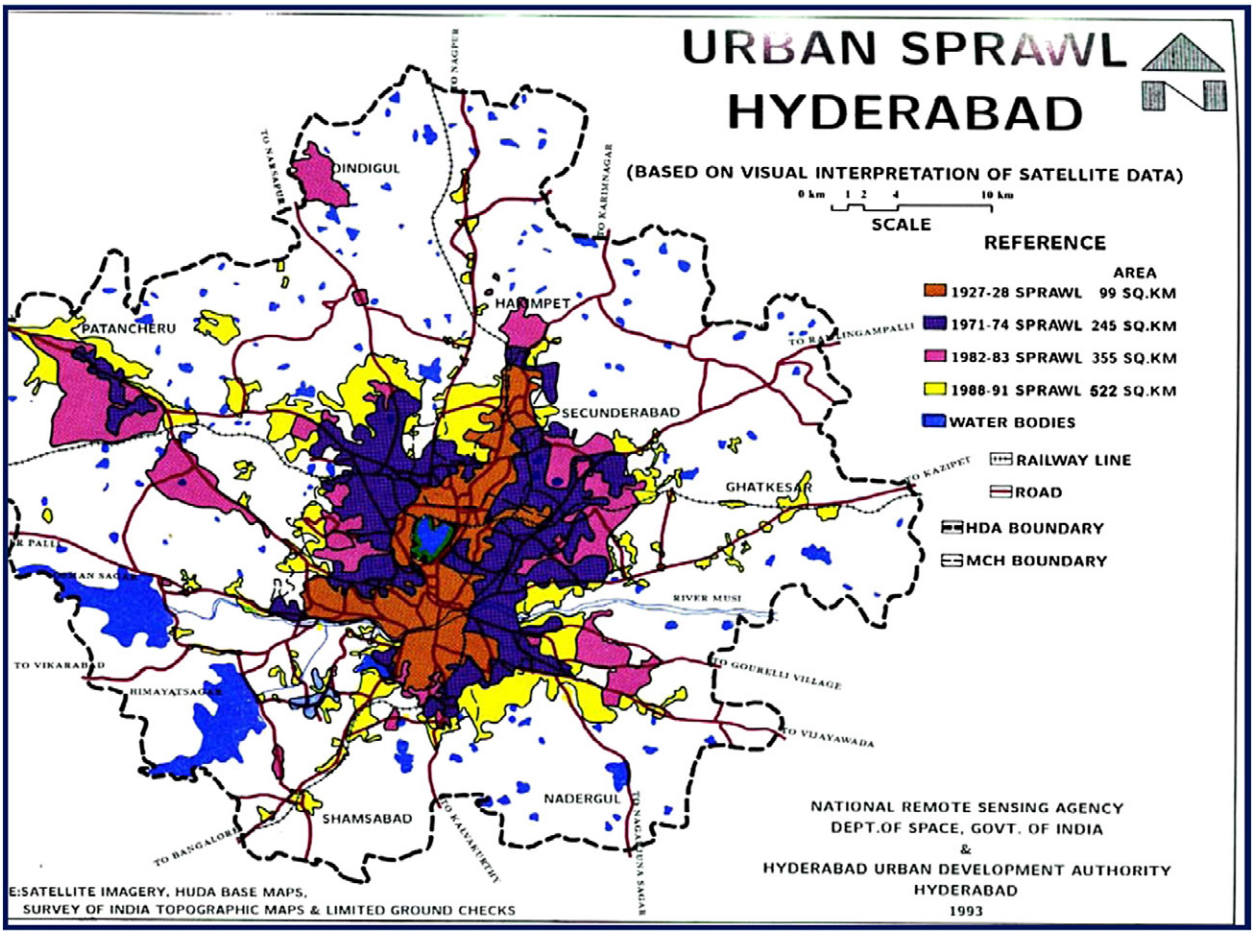

Fig. 3. Urban sprawl of Hyderabad city.

intensive demands on the environmental resources and poses problems by eating into valuable natural habitats of their hinterlands (OECD, 1990). Urban sprawl is associated with loss of natural wetlands along with loss of core forest habitat, loss of prime farmland and increase of impervious surface (Hasse and Lathrop, 2003). As the urbanization proceeds, the biological needs like water increase in complexity. As the local water resources like rivers, lakes and groundwater get increasingly polluted, the highly urbanized areas are forced to seek water from ever greater distances and expense (Detwyler and Marcus, 1972).

2.3. Vehicular pollution

Vehicular emission is the major contributor to the rising levels of all major pollutants. The transport sector is the major contributor to air pollution in urban India. With tremendous growth of public transport vehicles the problem is bound to become serious. The exhaust gas emitted by the internal combustion engine of public transport vehicles makes the city environment unpleasant (Agarwal and Singh, 2010). It is an issue of prime concern since these emissions are from ground level sources and thus have the greatest impact on the health of the population exposed to it. The increase in the number of vehicles contributes significantly to the total air pollution load in many urban areas. The number of motor vehicles in India has increased from 0.3 million in 1951 to 40.94 million in 1998 (MoST, 2000). CO (Carbon monoxide) and HC (Hydrocarbons) respectively account for 64% and 23% of the total emission load due to vehicles in all cities considered together (CPCB, 1995). Vehicular growth in Hyderabad during 2001is shown in Fig. 4 and break up of registered vehicles in HUDA area, 2002 is shown in Fig. 5. Fig. 6 shows the major industrial establishments in and around Hyderabad city.

Since this study focuses on the identification of main sources of PM from multidisciplinary point of view, the methodology used includes meteorological tools, interpretation of time series of PM levels (PM 10 & PM2.5) by using online air pollution monitoring system (using TEOM) and gaseous pollutants, chemical characterization of PM 10 & PM2.5 using Inductively Coupled Plasma (MS) and Chemical Mass balance Model 8.0 for Source Apportionment Studies.

2.4. Sampling site

2.4.1. Sampling measurement period

This work is based on the data collected during different seasons conducted in Punjagutta site, a critical traffic corridor,

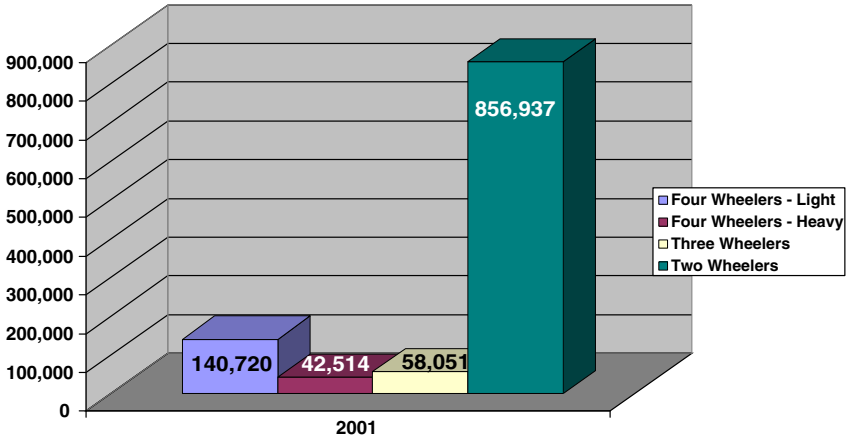

Fig. 4. Vehicular growth in Hyderabad during 2001.
Source: RTA, HYDERABAD.

during June 2004–May 2005. The measurements of both PM 10 and PM2.5 at the site were measured throughout the day and Meteorological parameters were measured 10 m above ground level as it is a continuous Monitoring Station. The PM10 and PM2.5 samples were collected in a month in such a way that PM10 samples were measured in the first two weeks of the month and then PM2.5 samples were collected in the remaining two weeks, remaining days again measuring the PM10 concentrations. The monitoring site was significant to this study both in terms of PM and meteorological data collection, uniquely located at the same elevation compared all other major Indian air quality monitoring locations.

The measurement site is located above a two-storey traffic police building and 5 m from the nearest busy street on which the average daily traffic density was about as high as 12,868 during peak hours. It is 14,567 between 9–10 am and 12,345 between 5–6 pm. It shows a slight fall at 19899 vehicles between 12 and1 noon. In this place also two wheelers accounted for high density. Location map of the online monitoring station is shown in the Fig. 7.

2.5. Monitoring station

2.5.1. Continuous PM2.5 & PM10 operations (TEOM's)

2.5.1.1. Particulate monitoring system. Particulate matter (PM10 and PM2.5) is measured using an R&P series 1400a TEOM particulate matter analyzer (Rupprecht Patashnick Co. and Inc., 2002). The main emphasis in ambient particulate monitoring is to determine the concentration of total particulates in the respirable and thoracic size ranges, since these have the greatest significance in relation to human health. Ambient air enters the particulate monitor through a sampling head, which has different collection efficiency for particles with an aerodynamic size distribution of less than 10 μm– the so-called PM10 fraction, PM2.5 and Total particulate matter. The PM10 size fraction encompasses a large proportion of respirable and thoracic particles. The particulate matter analyzer is composed of two components, the TEOM Sensor unit and TEOM control unit (Anjaneyulu et al., 2007a,b).

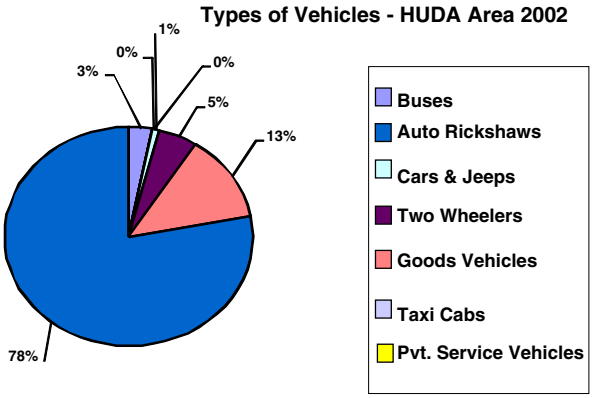

Fig. 5. Breakup of registered vehicles in HUDA area, 2002.
Source: RTA, HYDERABAD.

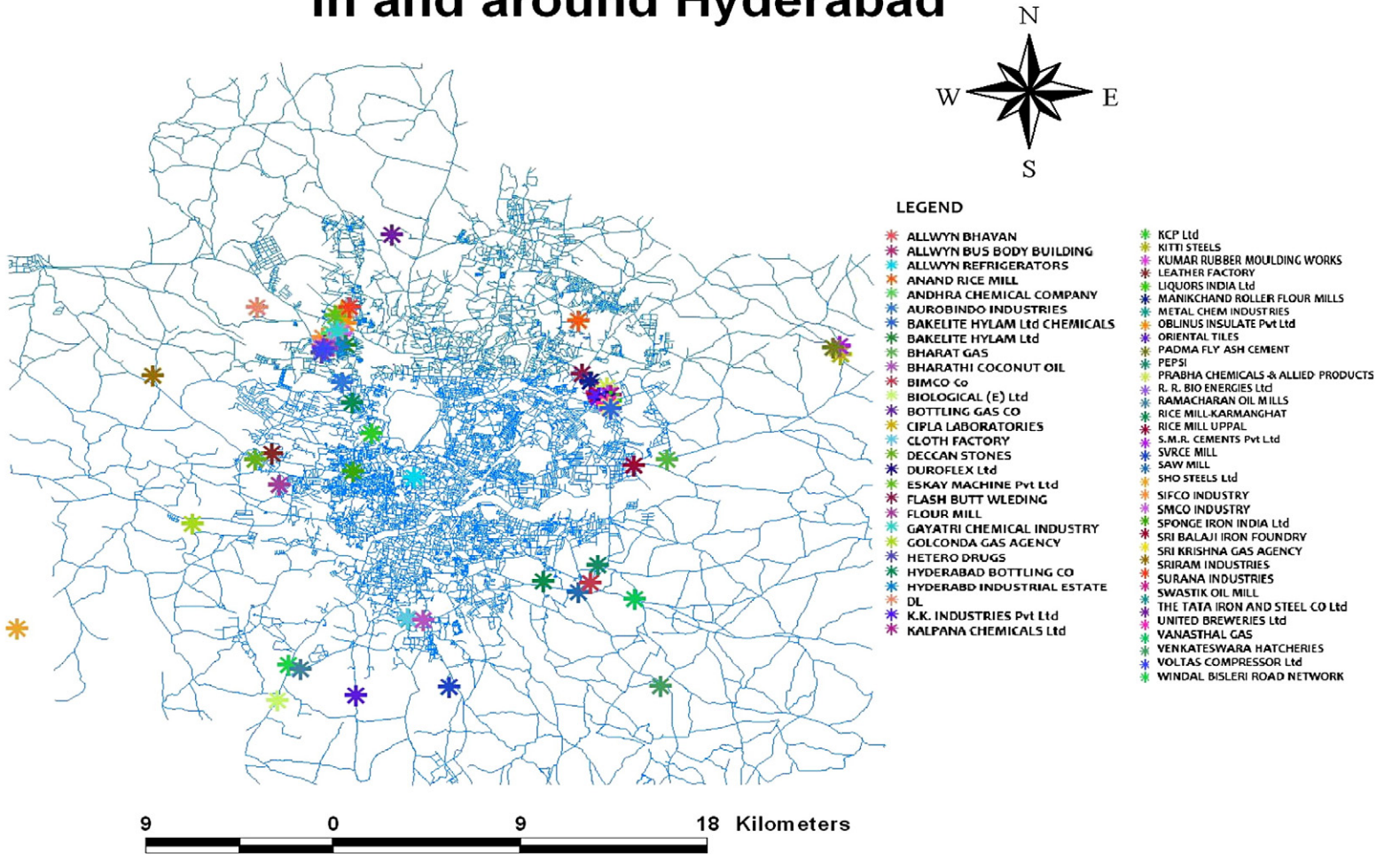

Fig. 6. Major industrial establishments in and around Hyderabad.

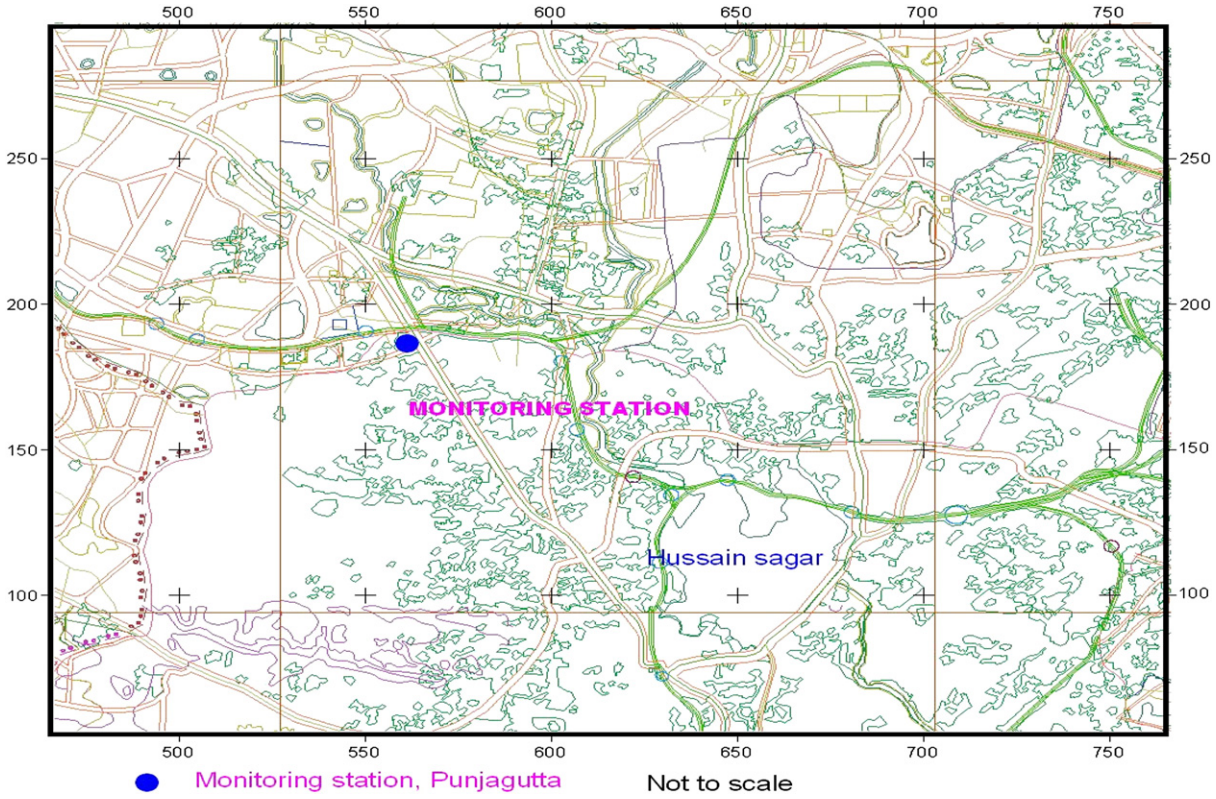

Fig. 7. Online air pollution monitoring station, Punjagutta, Hyderabad, India.

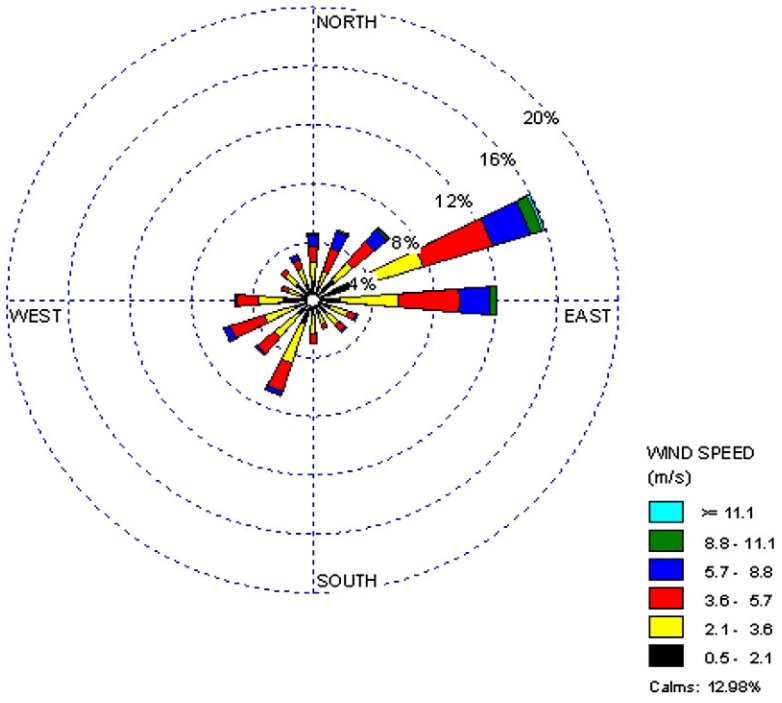

Fig. 8. Wind rose pattern of Hyderabad during June 2004–May 2005.

The airborne particle concentrations were detected continuously online by using a TEOM 1400a gravimetric particle analyzer, which uses a micro weighing technology that provides true mass measurements. The Series 1400a monitor incorporates an inertial balance that directly measures the mass collected on an exchangeable filter cartridge by monitoring the corresponding frequency changes of a tapered element. The sample flow passes through the filter, where particulate matter collects, and then continues through the hollow tapered element on its way to an active volumetric flow control system and vacuum pump (Patashnick and Rupprecht, 1991).

2.5.2. Description of the meteorological instruments

To accurately monitor weather conditions for predicting the dispersion of atmospheric pollutants requires reliable meteorological data. However, the problem is that conventional meteorological monitoring systems are inefficient and expensive. Further each sensor system in a weather station requires its own wiring and power supply requiring individual signal conditioning before being transmitted. A weather station, developed by Dallas Semiconductor, which transmits data by both power and bi-directional data over a single twisted-wire cable, is considered for the present online monitoring station (Anjaneyulu et al., 2007a,b). Fig. 8 shows the wind rose plot during sampling period. Fig. 9 shows the temporal variations of PM10.

2.6. Sample analysis

Currently there is no Indian Standard for analysing multiple elements in particles. Several studies in India have determined the ambient concentrations of some metals in particles although the methods used for sampling and analysis vary between studies. The acid soluble extracts are analyzed for As, Fe, Mn, Cu, Zn, Pb, Cd, Ni, Co, Cr, B and Se. The chemical components of acid soluble extracts are studied by Inductive Coupled Plasma (ICP MS), which gives the quantity of each metal present. The ICP studies have been carried out in Characterization Division, Center for Materials for Electronics Technology (C-MET), Hyderabad.

2.6.1. Analysis of toxic metals in particulate matter

Sampling occurred during a 1 year long measurement campaign (June 2004–May 2005). The PM10 and PM2.5 samples for inorganic metals were collected on a two week basis in a month, 4 samples on week days and 2 samples on week end days for the whole two weeks. To provide a better understanding of the sources contributing to PM 10 and PM2.5, six PM10 samples and six PM2.5 samples were collected every month and 72 PM10 and 72 PM2.5 samples were collected during the whole campaign.

PM10 & PM2.5 samples were collected over teflon-coated borosilicate glass fiber. It is assumed that PM deposited on the fiber filter paper is uniformly distributed over the entire collection area. The sample is digested with Concentrated HNO_3 to destroy the organic content.

2.6.2. Sample extraction

The extraction procedure was performed by hot acid extraction, as documented in Inorganic Compendium Method IO-3.1 (USEPA, 1999a,b). Subsequently, the extracts were analyzed using an Inductively Coupled Plasma/Mass Spectrometer (ICP/MS). This method allowed us to perform multi-element determination of trace elements. In this method, the extract solution is introduced by pneumatic nebulization into a radiofrequency-generated argon plasma where energy transfer

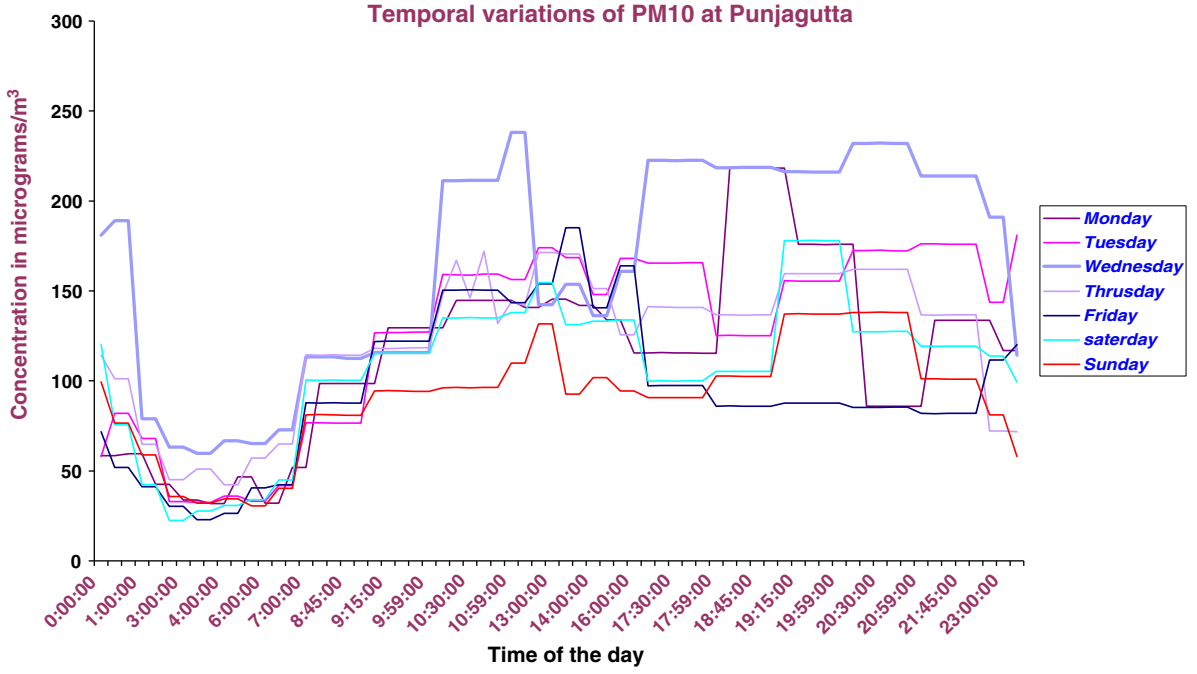

Fig. 9. Temporal variations of PM10 at Punjagutta Site, Hyderabad.

processes cause analyte desolvation, atomization, and ionization. The ions are extracted from the plasma through a differentially pumped vacuum interface and separated on the basis of their mass-to-charge ratio by a quadrupole mass spectrometer. The ions transmitted through the quadrupole are registered by a continuous dynode electron multiplier and the ion information is then processed by a PC-based data handling system. Interferences by polyatomic ions from gas, air, reagents, and sample matrixes were noted and corrected as appropriate (USEPA, 1999a,b). Detail information about the Uncertainties associated to ICP MS measurements and the corresponding detection limits is presented elsewhere (USEPA, 1999a,b).

2.7. Source apportionment of PM10 & PM2.5

Receptor modeling techniques were used for the source apportionment of PM10 and PM2.5. These techniques were applied to PM data collected at Punjagutta site, Hyderabad city, India. The receptor modeling techniques are based on the evaluation of data acquired at receptor sites, and most of them (those known as multivariable receptor models) do not require prior identification of emission sources (Henry et al., 1984; Srivastava et al., 2009; Karar and Gupta, 2007). These models have played a key role in the evaluation of PM sources with respect to national air quality standards in certain countries. In the United States, the Chemical Mass Balance model (Gertler et al., 1995; Chow et al., 1996) has been widely used, whereas in Europe receptor modeling techniques have mainly been based on methodologies that do not require chemical profiles of previously identified source emissions (e.g. Harrison et al., 1997a,b; Pio et al., 1996, 1998; Marcazzan et al., 2001).

Receptor models are based on the hypothesis that the bulk mass of PM can be considered to be the sum of independent contributing components: $PM = \sum^{n}_{i=1} PM_i$ (PM_i = mass concentration from the ith source; n = number of sources). Two main stages are distinguished in the multivariable receptor models: 1) source identification, and 2) estimation of source contribution. In the source identification process, a number of groups of chemical species of PM are differentiated on the basis of the degree of association or correlation between the analysed PM components. As regards the chemical species, each group is associated with a PM source. The source identification is usually based on the application of statistical tools, such as Principal Component Analysis (e.g. Sexton et al., 1985; Thurston and Spengler, 1985; Prati et al., 2000), Factor Analysis (Henry et al., 1984; Gordon, 1988) or Cluster Analysis (Sánchez and Ramos, 1987; Saucy et al., 1987). The quantitative determinations of the source contributions are usually based on multilinear regression analysis, in which the bulk PM concentration is used as a dependent variable, and a tracer of each source is employed as an independent variable. Chemical species of known origin or the absolute score factors obtained from the Principal Component Analysis are frequently used as source tracers (e.g. Thurston and Spengler, 1985; Hopke, 1991; Castro, 1997).

2.7.1. Theoretical foundations of receptor modeling

A summary of the main foundations of the multivariable receptor model used in this study is presented. For details on the mathematical developments, readers are addressed to the excellent reviews of receptor models presented by Henry et al. (1984), Thurston and Spengler (1985), Gordon (1988), Hopke (1985, 1991) or Castro (1997).

Receptor models are based on the equation of mass conservation:

$$C_{ij} = \sum_{K=1}^{m} = a_{ik}.S_{kj} \quad (1)$$

(i = 1..... n; j = 1..... N) n = number of chemical species constituting PM; N = number of samples (equivalent to days for 24-h samples); m = total number of PM sources; C_{jj} = concentration of the ith component in the sample jth; S_{ki} = mass of particles associated with the kth source during the sampling of the jth sample; a_{ik} = mass fraction of the ith component in the kth source.

The equation is expressed in terms of matrix:

$$C = A.S \quad (2)$$

Where C, A and S are matrixes of dimension n × N, n × m and m × N, respectively. The aim is to determine the matrixes A and S. The muitivariable receptor models assume that the variations in the PM component concentrations (C_i) are caused by variations in the contributions of each source. The model defines the most probable combination of sources which accounts for the variability in PM composition at the receptor sites. Thus, these models offer the advantage that they do not require prior knowledge of the number of PM sources or its chemical composition. However, limitations of these receptor models should be taken into account. Sources are identified on the basis of the correlation between the variations in the PM components levels. Thus, if any PM source presents a constant contribution during the study period, it is not detected. However, this is not likely if a relatively long sampling period is considered. Another limitation to be taken into account is the potential influence of factors which may induce correlated variations between PM components which do not result from the same source. In this case, the model would group these PM components in the same source, e.g. PM emissions from two sources located in the same direction with respect to the sampling site will be simultaneously transported to the receptor-sampling site under the same wind direction. Another drawback is that a relatively high number of PM samples are necessary, at least a minimum 30 samples in order to have statistical significance.

3. Results and discussion

Better understanding the PM measurement process and its dependence on location, time and other factors is important for both modifying regulations and better understanding its effects on health. In light of this, this paper reports the results from the detailed Particulate Matter analysis and investigations on the temporal and seasonal variability of different air pollutants along with the metals (PM10 & PM2.5). Based on these findings Chemical Mass Balance modeling was used to understand and quantify the major sources of air pollution in Hyderabad city. From June 2004 to May 2005, concentration levels of PM2.5 and PM10 were measured at 15 min intervals by the Punjaguta Online Monitoring Station – both the PM concentration levels varied highly. The daily averaged concentrations ranged from

40.9 to 499.5 μg/m^3 for PM10 and 31.1 to 285.5 μg/m^3 for PM2.5. Seasonal variations seemed to be largely affected by atmospheric conditions. The PM10 an9d PM2.5 data showed strong seasonal variations where PM10 showed higher concentrations during winter and lower concentrations during monsoon and PM2.5 showed lower concentrations during winter season.

3.1. Seasonal variation

For the investigation of the seasonal variation, the year was divided into three seasons: winter (October to January), summers (February to May), monsoons (June to September). The significant seasonal variations of particulate pollutants were obtained by using the monthly average concentration of PM10 and PM2.5 during the study period. Fig. 10 shows monthly concentrations variation of PM10 and PM2.5 at Punjagutta urban site. Table 1 and Table 2 shows the average seasonal concentration of PM10 and PM2.5 along with statistical analysis of chemical composition of PM 10 and PM2.5 respectively measured at Hyderabad from June 2004 to May 2005.

PM 10 concentrations exceeded the 24 h average USEPA, WHO and NAAQ standard of 150 μg/m^3, 50 μg/m^3 and 150 μg/m^3 many times in different months (Sep, Oct, Nov, Dec, Jan) during the study period. The averaged annual PM 10 measured concentrations in the site, however, exceeded US EPA, WHO and NAAQ annual standards of 50 μg/m^3, 20 μg/m^3 and 120 μg/m^3. PM2.5 concentrations exceeded the 24 h average USEPA, WHO and NAAQ standard of 35 μg/m^3 and 25 μg/m^3 many times in different months (Sep, Oct, Nov, Dec, Jan) during the study period. The averaged annual PM2.5 measured concentrations in the site, however, exceeded US EPA and WHO annual standards of 15 μg/m^3 and 10 μg/m^3.

The highest concentrations of aerosol mass are seen during the month of December. During the winter month of December, more stagnation and less rain scavenging occurs in cities like Hyderabad, causing aerosol particles to remain suspended over the city for an extended period of time. Also, the lower solar insulation rates during the winter months lead to lower atmospheric inversion layers where pollutants become trapped close to the ground, further increasing fine particle concentrations.

3.2. Source apportionment methodology

The sources of 12 metals (Mn, Cr, Cd, Cu, Co, Pb, Ni, Fe, Zn, Mg and Ca) for both PM10 and PM2.5 particles were determined. It is important to note that the source profiles for Indian cities have not been compiled. Thus, the metals source profiles used were taken from the USEPA Speciate 3.2, 2002 (USEPA, 2002) database. The emission sources considered were vehicles, industries, resuspended dust, combustion and refuse burning.

Source emissions of precursor gaseous and primary particles are highly variable in different air sheds due to differences in fuel use, raw material, operating conditions, and processes. Individual profiles shall be formed from individual samples, and the precisions of the numerator and denominator are propagated to assess the individual profile uncertainties. These individual profiles are further composite to obtain the source profiles formats to be used for CMB source apportionment. The study (Sharma and Patil, 1993) found that U.S. EPA source profiles are not suitable for highly polluted Indian regions and there is a need for the preparation of accurate source profiles for Bombay and other urban Indian regions. This would facilitate the source identification and apportionment of aerosols by receptor models like chemical mass balance.

3.3. Source identification

Source contributions from various sources in the PM10 and PM2.5 are provided in Fig. 11. Not all of the source profiles have been directly measured in Hyderabad, the model inputs serve as best estimates of the actual emission profiles based on the available data. However, tracer species are limited to a few characteristic tracers per source and so they are more specific to the sources than to the locations. It was also noted here that the identification of sources carries a lot less uncertainties than the quantification since CMB can over quantify source contributions.

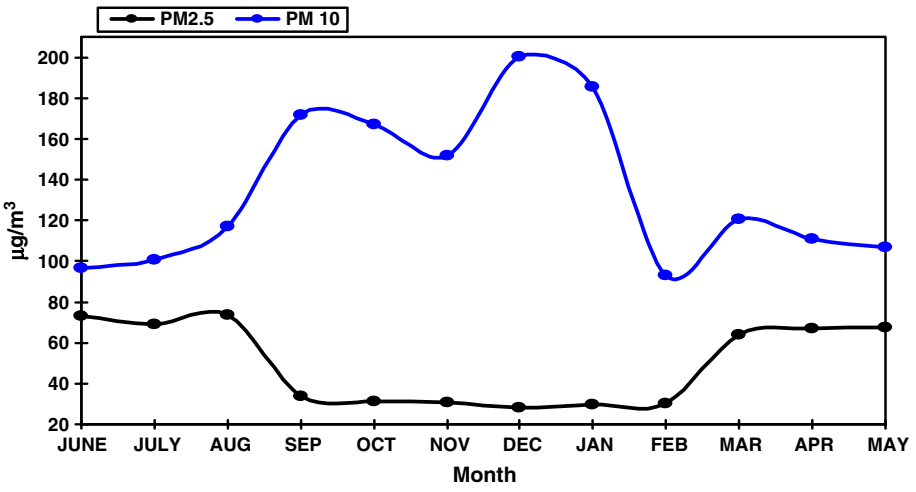

Fig. 10. Monthly concentrations variation of PM10 and PM2.5 at Punjagutta urban site.

Table 1
Summarizes the seasonal statistical analysis of chemical composition of PM10 measured at Hyderabad from June 2004–May 2005.

Parameter	Monsoon (μg/m^3)			Winter (μg/m^3)			Summer (μg/m^3)			Annual mean (μg/m^3)		
	Avg*	STD**	N***	Avg*	STD**	N***	Avg*	STD**	N***	Avg*	STD**	N***
PM10	121.370	34.715	56	176.070	21.249	56	107.848	11.624	56	135.100	37.919	168
As	1.132	0.455	24	0.780	0.083	24	0.685	0.139	24	0.866	0.322	72
Se	0.004	0.002	24	0.009	0.005	24	0.008	0.002	24	0.007	0.004	72
Zn	7.400	2.066	24	19.375	4.167	24	11.125	4.233	24	12.633	6.173	72
Cd	0.001	0.003	24	0.004	0.002	24	0.006	0.010	24	0.003	0.007	72
Pb	0.147	0.198	24	0.445	0.186	24	0.062	0.039	24	0.218	0.224	72
Co	0.010	0.006	24	0.009	0.126	24	0.003	0.002	24	0.007	0.086	72
Ni	0.008	0.005	24	0.119	0.008	24	0.005	0.004	24	0.044	0.007	72
Fe	0.067	0.089	24	0.283	0.144	24	0.037	0.485	24	0.129	0.329	72
B	12.693	0.047	24	12.060	0.050	24	12.665	0.018	24	12.473	0.054	72
Mn	0.054	4.260	24	0.136	3.793	24	0.057	1.170	24	0.082	3.056	72
Cr	0.062	0.048	24	0.178	0.114	24	0.017	0.020	24	0.086	0.097	72
Cu	0.025	0.039	24	0.089	0.066	24	0.008	0.007	24	0.040	0.054	72

*Avg = Average **STD = Standard Deviation ***N = Number of samples.

Monte Carlo analysis with Latin hypercube sampling (MC-LHS) was performed to evaluate the source impact uncertainties and quantify how uncertainties in ambient measurement and source profile data affect results. In general, uncertainties in the source profile data contribute more to the final uncertainties in source apportionment results than do those in ambient measurement data. Uncertainty contribution estimates suggest that non-linear interactions among source profiles also affect the final uncertainties although their influence is typically less than uncertainties in source profile data (Lee and Russell, 2007).

In PM10, resuspended dust is the dominant source (40%). In the case of PM2.5, Vehicle Emissions are the dominant (30%). The industrial contribution is more or less the same in both PM sizes i.e. 9% and 7% respectively. The Punjagutta site has small and medium open restaurants using wood and coal as fuel. These restaurants emit aerosols in minor fractions by combustion process which contributed an annual average of 12% and 9% for PM2.5. The refuse burning is a common site in the open areas of Hyderabad city. The refuse burning contributed 7% in PM10 and 6% for PM2.5. The results of this study will help in taking some useful decisions by the Hyderabad Municipal Corporation in burning refuse outside of the city which will decrease the particulate matter concentration in the city.

3.4. CMB model results

The absolute accuracy of CMB source contribution estimates is difficult to establish. Because these estimates are based on least squares linear regression, they are not unique (Chow et al., 1996). Pace and Watson, 1987, described several CMB performance measures and statistics, which may be used to evaluate the validity of CMB source apportionments. The model fit is considered is good if the values of the following statistical parameters lie within the acceptable range given along with them (Watson et al., 1997). The r^2 is the fraction of the variance in the measured concentrations that is explained by the variance in the calculated species concentrations (USEPA, 2001). The r^2 value ranges from 0 to 1.0. The closer the value of r^2 towards 1.0, the better the source contribution estimates explain the measured concentrations. The *R*/*U* is a signed

Table 2
Summarizes the seasonal statistical analysis of chemical composition of PM2.5 measured at Hyderabad from June 2004 to May 2005.

Parameter	Monsoon (μg/m^3)			Winter (μg/m^3)			Summer (μg/m^3)			Annual mean (μg/m^3)		
	Avg*	STD**	N***	Avg*	STD**	N***	Avg*	STD**	N***	Avg*	STD**	N***
PM2.5	62.2700	19.1883	56	29.9750	10.4750	56	57.1600	17.8834	56	49.8000	20.1800	168
As	0.0025	0.0030	24	0.0030	0.0025	24	0.0010	0.0022	24	0.0022	0.0024	72
Se	0.0002	0.0001	24	0.0002	0.0002	24	0.0005	0.0003	24	0.0003	0.0004	72
Zn	0.1215	0.1079	24	0.2005	0.1754	24	0.0798	0.1339	24	0.1339	0.1367	72
Cd	0.0006	0.0003	24	0.0077	0.0052	24	0.0029	0.0037	24	0.0037	0.0047	72
Pb	0.0788	0.0120	24	0.4185	0.4289	24	0.3165	0.2713	24	0.2713	0.3158	72
Co	0.0001	0.0023	24	0.0004	0.0117	24	0.0003	0.0002	24	0.0002	0.0086	72
Ni	0.0039	0.0000	24	0.0128	0.0004	24	0.0091	0.0086	24	0.0086	0.0003	72
Fe	0.0705	0.0236	24	0.5028	0.2993	24	0.0750	0.2161	24	0.2161	0.2640	72
B	2.2875	0.0042	24	2.9450	0.0514	24	1.7625	2.3317	24	2.3317	0.0376	72
Mn	0.0045	0.9521	24	0.0468	1.3680	24	0.0217	0.0243	24	0.0243	1.1148	72
Cr	0.0086	0.0054	24	0.0061	0.0038	24	0.0063	0.0070	24	0.0070	0.0037	72
Cu	0.0062	0.0036	24	0.0020	0.0024	24	0.0486	0.0189	24	0.0189	0.0277	72

*Avg = Average **STD = Standard Deviation ***N = Number of samples.

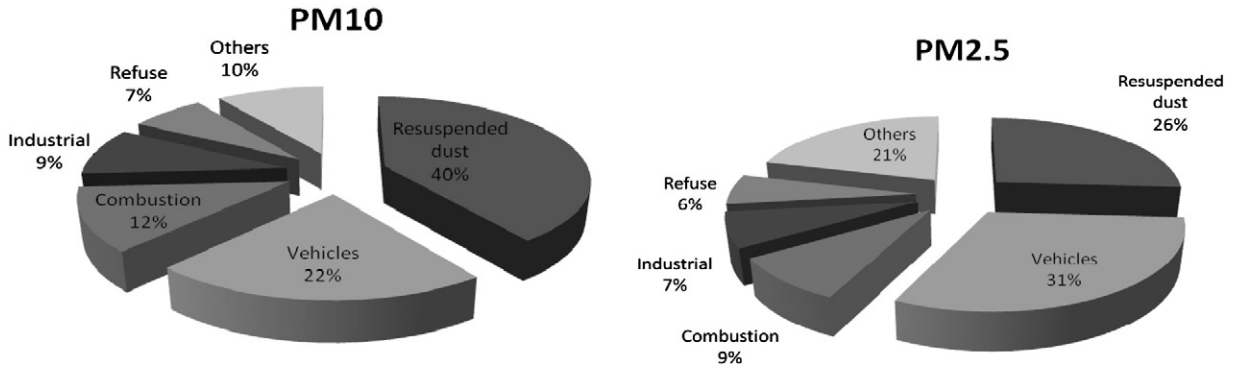

Fig. 11. Source contribution to PM10 and PM2.5.

difference of measured and calculated concentration of species (residual), divided by the uncertainty of that residual. Acceptable values of *R/U* range from 0.5 to 2. Positive values of *R/U* indicate that one or more profiles are contributing significantly to that species. Negative value of *R/U* is indicative of insufficient contribution to that species and a source may be missing (Srivastava et al., 2005; USEPA, 2001). The chi-square value (χ^2) is a weighted sum of squares of the difference between calculated and measured fitting species concentrations and should be equal to 1 for a very good fit. Values between 1 and 2 are acceptable and values greater than 4 indicate that one or more species concentrations are not well explained by source contribution estimates. Percent mass is the percent ratio of the sum of the model-calculated source contribution estimates to the measured mass concentration. Percent mass ranging from 80% to 120% represent good fit to the data. Degree of freedom equals the number of fitting species minus the number of fitting sources. Degree of freedom must be greater than 5 as per EPA (environmental protection agency) target (Ward and Smith, 2005).

3.5. Chemical mass balance model

Table 3 gives the R^2 values along with the range of ratio R/U and χ^2 values. The results from the source apportionment calculations show strong agreement for PM10, with a correlation slope of 0.92 and a correlation coefficient (R^2) of 0.96. Agreement for PM2.5 was similarly good, with a correlation slope of 1.21 and a correlation coefficient (R^2) of 0.92.

4. Conclusions

This study investigated the contributions of different emissions sources to PM10 and PM2.5 aerosol mass in Hyderabad city using CMB Model. From CMB calculations, 5 major sources have been identified for both PM10 and PM2.5. Results of CMB Model showed that major source throughout the study period were resuspended dust (40%) for PM10 and 31% for PM2.5. Vehicles has also contributed significant influence on particulate emission at the site for both PM10 (22%) and PM2.5 (31%). It has been observed that the over-dominance of vehicular pollutants was confined to PM2.5 particles than PM10, while they dominated both PM10 and PM2.5 during pre-CNG implementation period (2001) in Delhi (Srivastava and Jain, 2007). Other major identified sources of particulate matter were industrial emissions, combustion and refuse burning. Better understanding of source contributions to ambient particulate matter levels is needed to develop traffic control strategies. The results of this study have resulted in construction of fly over the junction of the Punjagutta site which made low traffic congestion.

Table 3
CMB performance statistics during study period.

Size	R^2	R/U	χ^2	Percent mass	Degree of freedom
PM10	0.96	0.92	1.21	110.30	30
PM2.5	0.92	1.21	0.88	96	14

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