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Contribution of Vehicular Activity to Air Pollution in Hyderabad, India: Measurements, Chemistry and Analysis

Sarath K. Guttikunda*, Rakesh Aggarwal#
*Affiliate Assistant Research Professor, Desert Research Institute, Reno USA, and
Urban Emissions Info, J-1858, Chittaranjan Park, New Delhi, India 110019
Email: sguttikunda@gmail.com; Phone: +91 9891315946
#Envirotech Instruments Pvt. Ltd, A-271, Okhla Industrial Area, Phase -1, New Delhi, India 110020

Abstract
In this paper, an analysis of data from continuous ambient air monitoring station in Hyderabad is reported to better understand daily and seasonal trends of particulates and chemistry of ozone pollution in the atmosphere. The objective of the paper has been to investigate the contribution levels of transport emissions to ambient air pollution levels via monitoring data, source apportionment of filter samples for particulates, and dispersion analysis. Overall, transport sector is expected to contribute ~50 percent to ambient PM pollution in the form of direct emissions, ~30 percent in the form of indirect PM pollution, and high contributions to Ozone and Carbon Monoxide along the main activity corridors. A series of interventions relevant to Hyderabad, focused on transport sector are discussed.
Keywords: Hyderabad; Transport; Source Apportionment; Chemistry; Air Monitoring

1.0 Introduction

Hyderabad, a 400 years old city, is the state capital of Andhra Pradesh, India, and the fifth largest city in India with a population nearing 7 million. The twin cities of Hyderabad and Secunderabad of Municipal Corporation of Hyderabad (MCH) and the neighboring ten municipalities together form Hyderabad Urban Development Area (HUDA), a major high-tech center, with increasing economic activity.

Air pollution poses a serious problem in HUDA due to its direct impact on human health, such as increased incidences of chronic bronchitis, cancer of the respiratory tract, asthma, and induced mortality (APPCB, 2006). Increase in motorization (with ~600 vehicles added to in-use fleet per day) and industrial emissions (local and global) has resulted in deteriorated urban air quality. Increase in the incidence of morbidity and mortality due to air pollution (IES, 2004, APPCB, 2006, and IES, 2008) has prompted public awareness campaigns for better air quality management. This paper presents results from the on-going air quality monitoring studies and source apportionment analysis, highlighting contribution of transport sector in the city.

2.0 Air Quality and Transport

In HUDA, 20 monitoring stations are installed both in polluted hot spots and background sites, measuring respiratory PM, sulfur dioxide (SO_2), and nitrogen oxides (NO_x). Figure 1 presents annual average concentrations of PM_{10} (averaged over all stations in the city) for the last 10 years. In 2007, PM_{10} concentrations in the city averaged to ~120$\mu g/m^3$. This level is above threshold for health impacts (WHO, 2006). Although averaged concentrations during the recent years show a value lower than those measured in 1999, the hot spots in the city measure ~2 times the city averages presented here. This lowering of the average values is mainly due to the increase in the number of monitoring stations across HUDA boundaries since 1999, while in 1999 most of the measurements were made at the hot spots. The relocation of the industries in the early 2000's along with improvements in the energy efficiency of new constructions was also responsible for the slower rise in the annual average concentrations presented in Figure 1. The main reason, however, for reduction in PM pollution in the early 2000s, was an ordinance to replace petrol based 3-wheelers with liquefied petroleum fuel (LPG), and relocation, shutting down, and merging of some industries falling within the now earmarked residential zones. Over a four year period, concentrations reduced from 128$\mu g/m^3$ in 1999 to 83 $\mu g/m^3$ in 2002. However, the recent increase in passenger cars and 3 wheelers (petrol, diesel, and LPG; 2

stroke and 4 stroke) has nullified the impact of this conversion. Currently, only 40 percent of the ~80,000 3-wheeler fleet is LPG based.

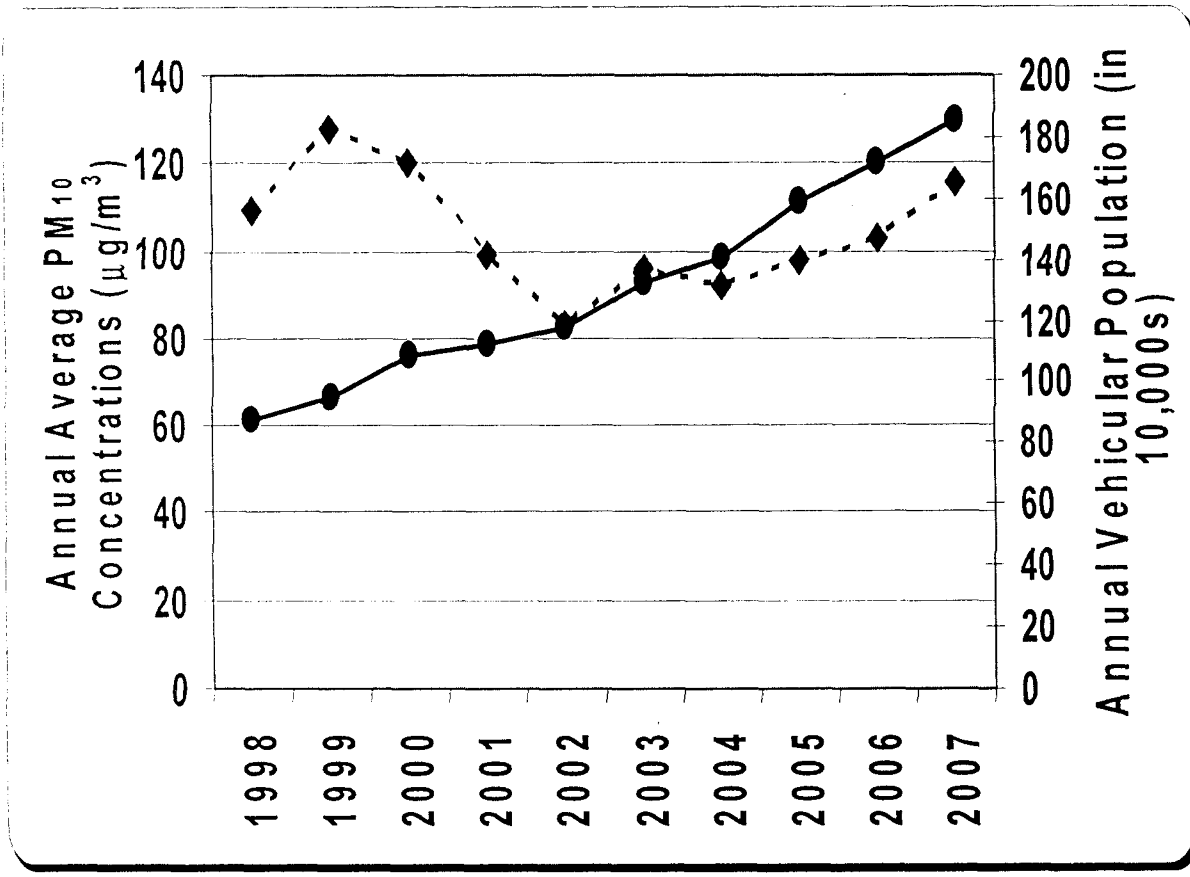
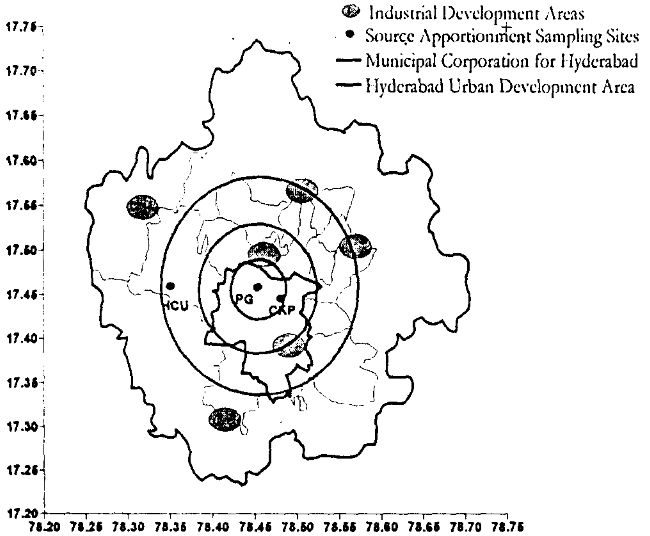


Figure 1: Annual average air quality and vehicular population trends in Hyderabad,

The in-use vehicular population presented in Figure 1 grew from 1.45 million vehicles in 2001 to 2.0 million vehicles in 2007. Of the total, 2 wheelers (2-stroke and 4-stroke) dominate with a 79 percent share and passenger cars (petrol and diesel) at ~230,000. The passenger cars are estimated to grow at ~10 percent a year. The public transport system operates ~15,000 point to point buses with good frequency. It includes buses and some 3-seater and 7-seater auto rickshaws. All the buses and goods vehicles run on diesel. The average age of the diesel fleet (for both public transport buses and goods vehicles) is high (~10 years). Also, lack of effective inspection and maintenance programs lead to higher emission levels from these vehicles. Added to this, reduced operating speed for public transport on main roads, because of increasing number of personal vehicles, results in higher pollution levels due to idling. This happens because of congestion due to increased on-street parking; encroachments by hawkers; and stopping of vehicles in the middle of the road (especially autos and buses) to service their passengers, in spite of a number of flyovers connecting and by-passing major choke points in the city. Furthermore, in the city non-transport sector is also prevalent in the form of steel, textiles, paper, pharmaceuticals, and paint industries in the five large industrial development estates (represented by elliptical circles in Figure 2). These are located within 10 km radius of the city. In 2005, the number of these industries were listed at ~390 following the new industrial and residential zoning in HUDA.



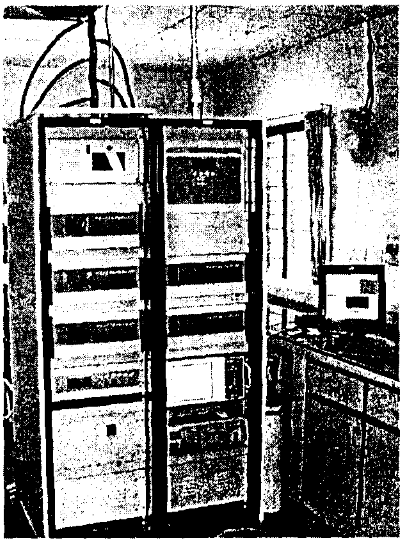


Figure 2: In the right is the geographical location of Hyderabad Urban Development Area (HUDA) marked with major industrial development areas (IDAs) and in the left is shown the continuous Ambient Air Quality Monitoring Station.

3.0 Contribution of Transport Sector

3.1. Analysis of Monitoring Data

In the city of Hyderabad a continuous monitoring station (Figure 2) is operated on the premises of APPCB. This is the first station setup under the Supreme Court mandated program to set up Continuous Ambient Air Quality Monitoring Stations (CAAQMS) in sixteen Indian Cities. The station uses US EPA Certified Analyzers for monitoring PM_{10}, CO, SO_2, NO_x, Ozone, Benzene – Toluene – Xylene (BTX) and a host of meteorological parameters. The pollutants of interest in the present study are PM_{10}, NO_x, BTX, CO, and Ozone, since all of them have direct linkages to emissions from the transport sector. Data collection rate from this centre is above 95 percent, making it reliable over a large time frame for analysis and policy support.

Particulates (PM), especially the fine fraction, are of primary concern for most of the city pollution regulations due to their direct impact on human health (HEI, 2004). However, other pollutants are also as important, because their presence results in secondary contribution to PM pollution. For example, SO_2 and NO_x emissions, following chemical transformation contribute significantly to fine PM fraction; and in urban studies this secondary contribution is expected to be as high as 40 percent.

Figure 3 shows typical variations of NO, NO_2, NO_x, CO and Ozone (O_3) over a twenty four hour period for November 25^{th}, 2005. As expected, the monitoring data (Figure 3) shows the pronounced peaks coinciding with the morning and evening traffic hours, indicating that the predominant source of these pollutants at this site is related to traffic. Following increase in the emissions of NO_x and CO during rush hour, Ozone concentrations also build up rapidly after sunrise and soon reach a maximum. This maximum is followed immediately by reduction in NO_x and CO concentrations owing to oxidation by Ozone present near ground. In the evening, a reverse phenomenon is observed. The photo-chemical activity is reduced at sunset, which increases CO and NO_x concentrations owing to availability of less Ozone for initiation of oxidation process.

Although urban photochemistry is well known, some of the aspects of chemistry that relate to ozone sensitivity and indicator species is worth summarizing. The ozone producing reaction sequence is initiated by the reaction of hydrocarbons (RH) with hydroxyl (OH) radicals, followed by reactions with NO producing NO_2. The conversion of NO to NO_2 results in the production of O_3 through photolysis and formation of the intermediates $O(^3P)$ (ground state oxygen atoms) and O^1D photolysis (excited oxygen atoms) as represented in Equation 1. In these equations, radicals are indicated with a closed dot next to each species.

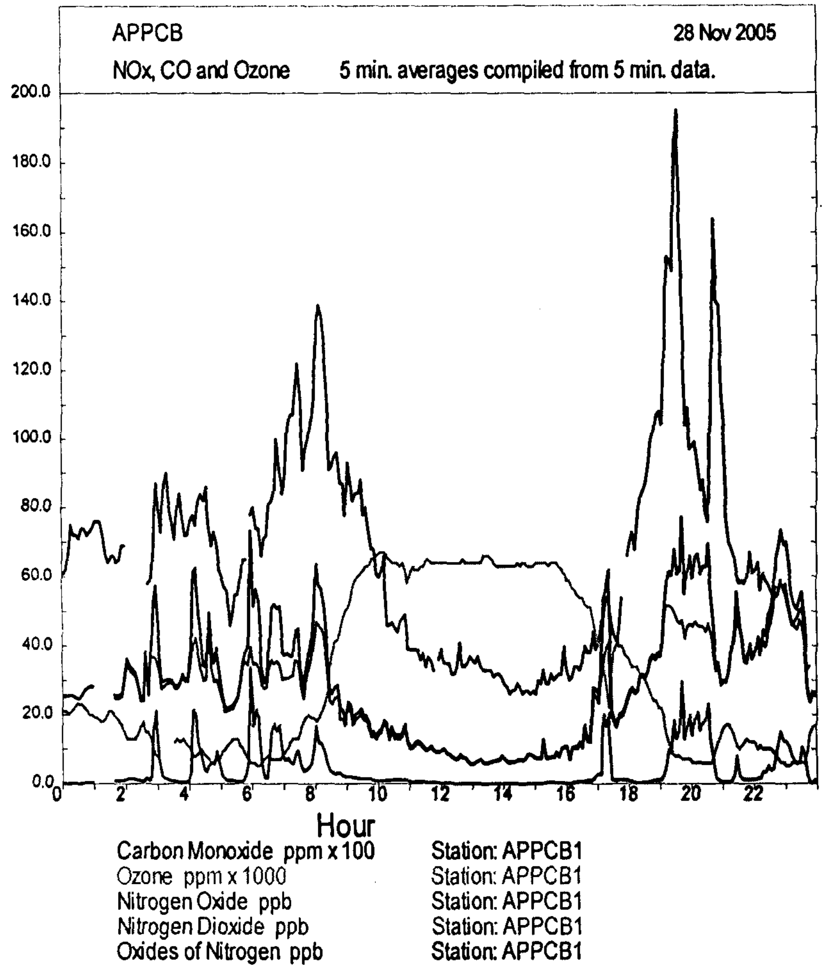


Figure 3: Time series plot of NO_x, CO and Ozone on a typical day

$$RH + OH \rightarrow R^{\bullet} + H_2O$$
$$R^{\bullet} + O_2 \rightarrow RO_2^{\bullet}$$
$$RO_2^{\bullet} + NO \rightarrow RO^{\bullet} + NO_2 \qquad \textbf{(Equation 1)}$$
$$NO_2 + hv \rightarrow NO + O(^3P)(\lambda \leq 400nm)$$
$$O(^3P) + O_2 \rightarrow O_3$$

In polluted environments, as measured in case of Hyderabad, CO also contributes to ozone production via reaction with OH radicals and subsequently with NO.

$$CO + OH \rightarrow H^{\bullet} + CO_2$$
$$H^{\bullet} + O_2 \rightarrow HO_2^{\bullet}$$
$$HO_2^{\bullet} + NO \rightarrow HO^{\bullet} + NO_2 \qquad \textbf{(Equation 2)}$$
$$NO_2 + hv \rightarrow NO + O(^3P)(\lambda \leq 400nm)$$
$$O(^3P) + O_2 \rightarrow O_3$$

Besides, anthropogenic origin, CO is also generated by the transport sector during the chemical conversion of hydrocarbons resulting in net production of O_3. One of the important intermediate products is formaldehyde (HCHO), which is very short lived, undergoes photolysis in the daytime converting to CO, NO_2 and hydrocarbon radicals which result in net production of O_3. Major sources of HCHO in a polluted boundary layer are the chemical conversion of Alkanes (e.g., Methane, Ethane), and Alkenes (e.g., Ethene). Major source of hydrocarbons is the incomplete combustion in the vehicles owing to improper maintenance to even adulteration of the fuel, among many possible reasons.

$$CH_4 + NO + OH + 2O_2 \rightarrow HCHO + HO_2^{\bullet} + H_2O + NO_2$$
$$C_2H_4 + OH \rightarrow HCHO + RO_2^{\bullet}$$
$$HCHO + hv + 2O_2 \rightarrow CO + HO_2^{\bullet}(45\%) \qquad \textbf{(Equation 3)}$$
$$HCHO + hv \rightarrow CO + H_2(55\%)$$
$$HCHO + OH^{\bullet} + O_2 \rightarrow CO + HO_2^{\bullet} + H_2O$$

However, in an urban environment, in NO_x rich conditions, NO also reacts with O_3 producing NO_2 and HNO_3, determining the steady state concentration of ozone called photo-stationary state reaction. As is the case at the monitoring site in Hyderabad, the net production of NO_2 in the city is much higher, reaching a steady state ozone concentration of ~60 ppbv during the day time.

In remote areas, with lesser transport quotient, reaction of NO and O_3 is slower, resulting in net production and transport of O_3. Also, RH's and NO_x species compete for the reaction with OH molecules. On the other hand, in an area, where VOC (including CO) to NO_x ratio is higher, reaction of RH with OH radicals dominates generating new intermediate radicals and accelerating O_3 production. The later scenario is more plausible in an industrial zone with solvent extraction units resulting in higher VOC emissions than NO_x.

Ozone is a strong oxidant and can lead to respiratory problems in humans, as well as affect plant life. Growing number of vehicles in the city with increasing emissions, ground level ozone is now entering the health hazard zone along the main activity corridors, which needs policy interventions. However, in an urban environment, besides Ozone and CO, particulates (PM) still remain of the primary concern.

Figure 4 present seasonal and annual average ambient concentrations of PM_{10}, CO, and Benzene measured at the CAAQM station in Hyderabad. It is seen that in the city the night time concentration of PM is of a growing concern. Main conclusions based on Figure 4 are:

i) Night-time concentrations of PM particularly in the winter and spring seasons are approximately twice the day time levels. This is primarily for two reasons. The truck traffic is not allowed in the city during the daytime, however, they ply on the highway close to the monitoring station resulting in a drastic increase in the emission levels. All the heavy duty trucks are diesel based with an average age of at least 5 years. Also, lower mixing heights and poor ventilation in the nighttime prevents proper dispersion of these pollutants, causing a buildup of pollutants.

ii) Peak Concentrations of all of these pollutants occur early in the morning coinciding with the morning traffic hours.

iii) Annual mean concentrations of CO and Benzene are within proposed national standards but short term peak concentrations are several times higher.

CAAQMS data thus indicate that planners and regulatory agencies will have to look beyond 24 hour averages and annual averages if exposure of citizens is to be avoided.

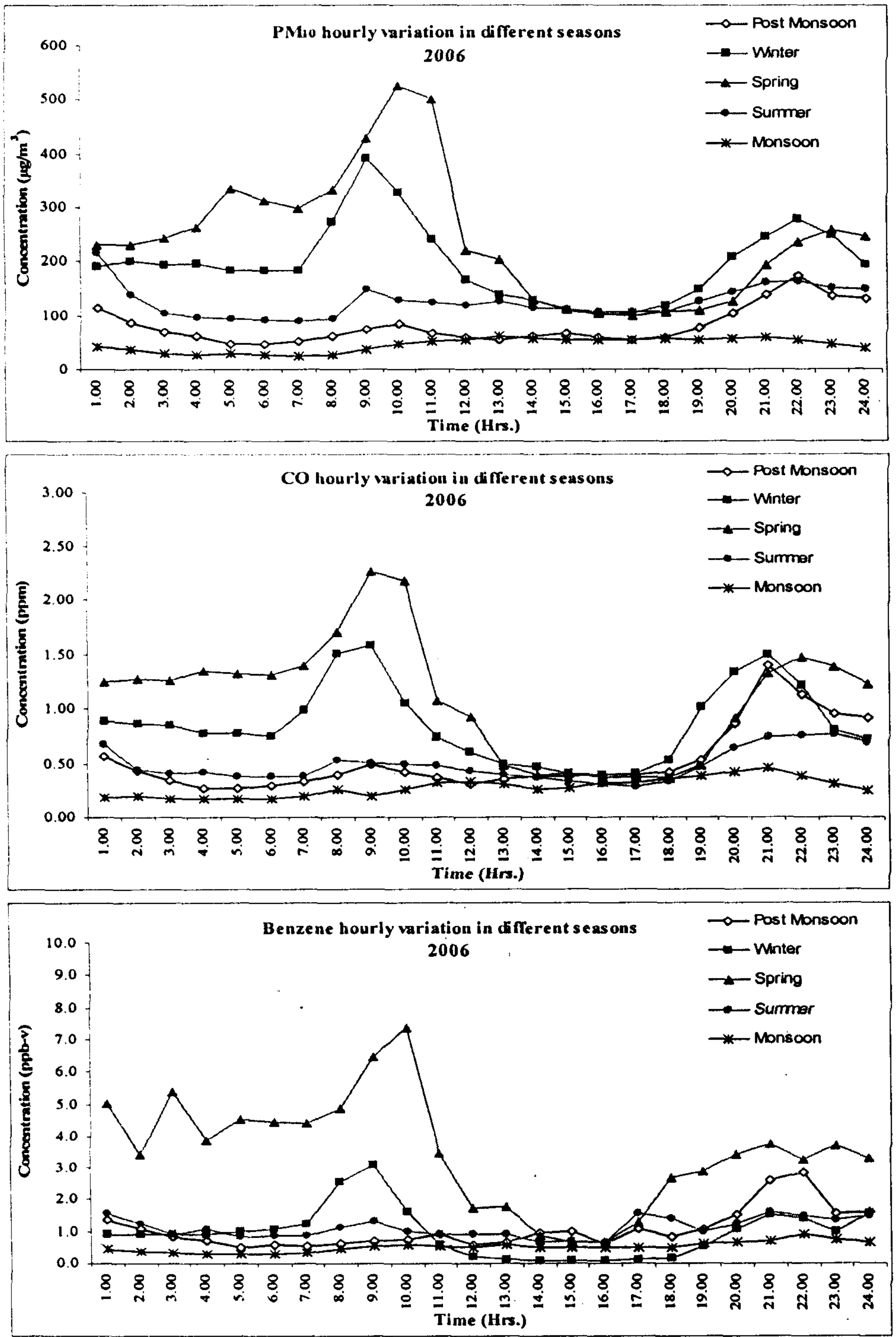


Figure 4: Seasonal variation of PM_{10}, CO, and Benzene in 2006

3.2. Filter Sampling and Receptor Modeling

In August 2003, following the Honorable Supreme Court's order, Andhra Pradesh Pollution Control Board, in collaboration with the Desert Research Institute (Reno, USA) co-financed from the USEPA Integrated Environmental Strategies program (Washington DC, USA), and the World Bank (Washington DC, USA), conducted a year long source apportionment study covering three seasons between November 2005 and December 2006. A detailed description of the study methodology, analysis, and results is presented in IES, 2007.

The sampling was carried out using AirMetrics MiniVol samplers at three locations presented in Figure 2. Punjagutta (PG) is an urban site dominated by transport, Chikkadpally (CKP) is also an urban site dominated by industrial and residential sources, and Hyderabad Central University (HCU) is a background site on campus. Following the sampling, composition of PM was determined by analyzing the parameters: ions (anions and cat-ions), crustal elements, organic and elemental carbon fractions, and heavy metals; and by conducting receptor modeling using CMB version 8.2. A summary of receptor modeling results presented in Figure 5 conclude that more than half of all observed PM in Hyderabad can be attributed to vehicular activity (direct vehicular exhaust and indirect fugitive dust due to resuspension on roads). The fugitive dust is predominant in the coarser PM_{10} fraction due to its larger particle size while the industrial sources dominate the finer $PM_{2.5}$ fraction. The secondary PM due to chemical transformation of SO_2 and NO_x emissions from coal and diesel combustion has been included in the fine fraction.

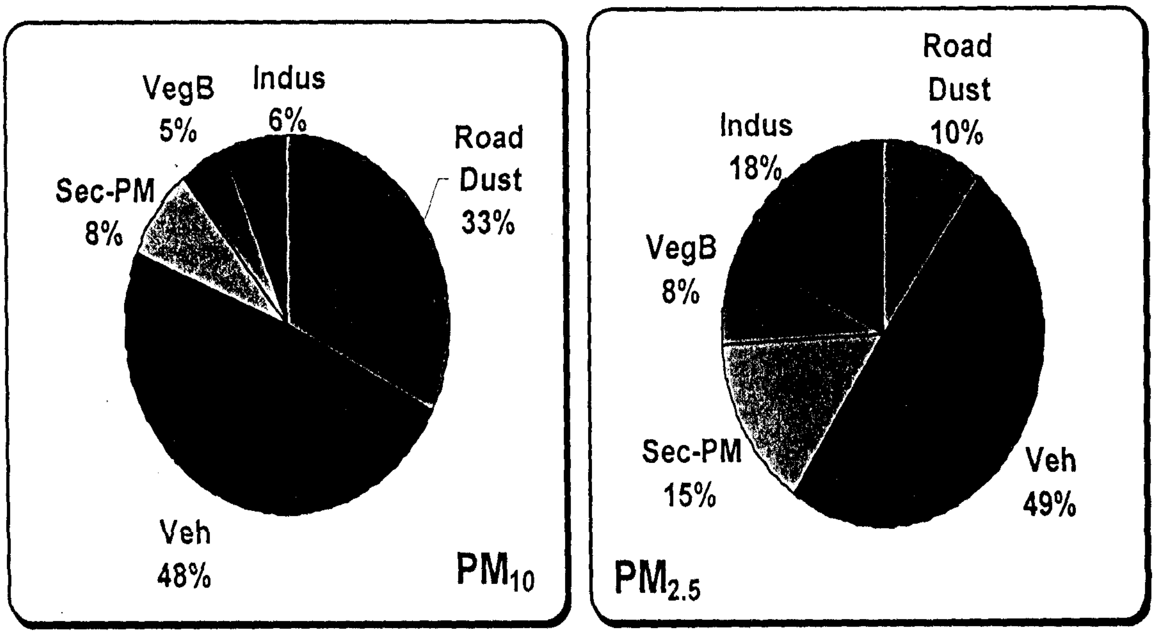


Figure 5: Estimated average sectoral contributions based on source apportionment study in Hyderabad, India during November'05 to November'06

3.3. Emission and Dispersion Modeling

Abatement of air pollution is one of the biggest challenges and presents a clear need for better understanding of sources of air pollution and their strengths. Following the source apportionment study in 2005-06, an emissions inventory was established for the base year 2006 for pollutants PM_{10}, SO_2, NO_x, and CO_2. A consolidated exercise of bottom-up and top-down approaches established a baseline for validating the estimated emissions and projections for future years (IES, 2008; Guttikunda et al., 2008). The emission inventory was established using existing fuel consumption and activities data by inserting applicable emission factors for transport and industrial sectors in Hyderabad (Reddy et al., 2001; Gurjar, et al., 2004; HEAT, 2004; CPCB, 2007; SEI, 2006) for the base year 2006.

Overall, PM emissions are dominated by vehicular, industrial, and fugitive sources. The garbage burning, a very uncertain source of emissions due to lack of necessary information on the amount burnt and proper emission factors, is a significant unconventional source. Only one landfill to the southeast of MCH border is estimated to burn on average 5 percent of the trash collected and combined with the domestic fuel consumption, it accounts for ~10 percent of the annual PM_{10} emissions. Emissions of PM_{10}, SO_2, NO_x, and CO_2 are estimated at 29.6 ktons, 11.6 ktons, 44.5 ktons, and 7.1 million tons respectively. For CO_2, a major GHG gas, the transport sector accounts for 90 percent of the emissions.

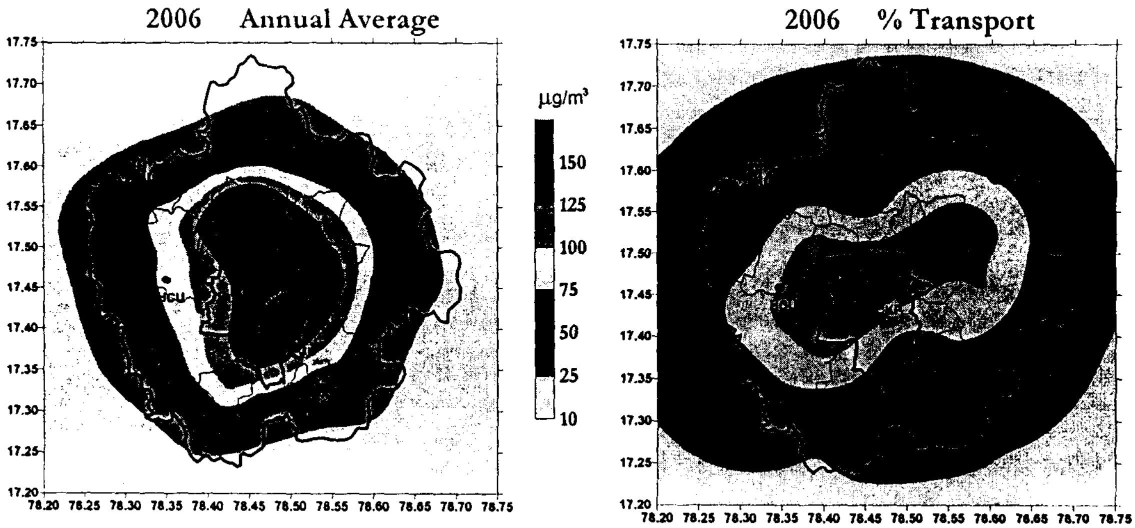


Figure 6: Modeled annual average PM_{10} concentrations from 2006 & percent contribution of transport sector

For dispersion of emissions, the Atmospheric Transport Modeling System (ATMoS) (Calori, et al., 1999; Guttikunda, et al., 2003) was utilized with meteorological data from NCEP Reanalysis fields for the grid containing Hyderabad. The main city center was divided into a 20 x 20 grid based on geographical information from the city council. Note that the distribution of emissions to the grids was subjective where real location information was not available, especially for non-industrial sources and was based on geographical maps of population and road networks. The estimated annual average concentrations presented in Figure 6, include both primary PM and secondary PM due to chemical conversion SO_2 and NO_x emissions to sulfates and nitrates.

In the HUDA region, on an average, secondary PM contributes 20-40 percent of total PM_{10}. The estimated annual average concentrations were calibrated against the measurements for the year 2006 with the urban hotspots averaging ~200 µg/m³ on a daily basis. The highest concentrations in Figure 6 represent the areas with highest industrial density; while largest density of the population is within the 10 km radius and MCH boundary lines. The ambient concentrations for HUDA urban area are frequently above the national ambient guidelines. Within the MCH boundary, in 2006, the contributions of individual sectors ranged between 20-50 percent for vehicular sources (also presented in Figure 6), 40-70 percent when combined with road dust, 10-30 percent for industrial sources, and 3-10 percent for domestic and garbage burning sources (IES, 2008).

4.0 Conclusion

Road transport is the key source for many air pollutants, particularly in the growing cities like Hyderabad. The series of on going studies based on monitoring (CAAQMS), source apportionment studies, and bottom up analysis via emissions inventory and auditing, suggest that the transport sector in Hyderabad, needs special attention and the local governing bodies need to make special provisions to prevent and control the growing pollution due to this sector.

The trend in the transport sector is that the new vehicles are becoming individually cleaner in response to emission standards legislation, but total number of vehicles and vehicle kilometers traveled are increasing, which is nullifying any efforts by the governing bodies to control emissions by command. Promising areas of improvement are (a) introduction of an effective inspection and maintenance program for all types of vehicles, starting with public transport and goods vehicles (especially diesel based vehicles); (b) improving the quality of fuel by decreasing the sulfur content of diesel to reduce SO_2 emissions – a precursor to secondary PM; (c) introducing stricter regulations against fuel efficiency of the vehicles on the supply side of the road transport; (d) promoting public transport and increasing access to public transport via infrastructure development for bus rapid transport and metro rail systems; and last but not the least (e) promoting non-motorized transport in the cities by building walkways and bikeways.

Among the fuel substitution options, LPG and compressed natural gas (CNG), appears to be a relatively wide-scale method of reducing local pollution in the transport sector, provided availability of the necessary infrastructure to supply and administer at larger scales is assured. LPG is primarily suited to cars and small petrol vehicles. Currently ~40% of the petrol based 3-wheelers are retrofitted to use LPG. CNG is suited for light duty trucks and heavy duty buses in the public transport, but the supply chain is limited in Hyderabad. Currently five public transport buses are in testing phase with a supply of 3 tankers of CNG every day from filling stations in Vijayawada. With these alternative fuels, cost benefits, are mainly applicable where high mileages are the norm, such as public transport buses and taxi services.

Among the non-road transport interventions, fugitive dust due to entrainment is the major source of air pollution. This intervention is for 100 percent local health benefits. The city officials in the recent past have piloted heavy machinery sweepers followed by wet sweeping to control dust loading on roads. These machines are operated at the night time. This intervention, however, needs more institutional and financial support for scale-up.

Congestion pricing in the urban centers is among the first of the economic measures successfully implemented in the cities of London, UK and Stockholm, Sweden. Congestion pricing is the practice of charging motorists to use a roadway, bridge, or tunnel during periods of the heaviest use. HUDA authorities are in the process of conducting a feasibility study. Its purpose is to reduce automobile use during periods of peak congestion, thereby easing traffic and encouraging commuters to walk, bike, or take mass transit as an alternative. Hyderabad city operates a light rail transportation system known as the Multi Modal Transport System covering 27 stations with a rail length of 43 km. At present an estimated 70,000 commuters use this service everyday. City is planning to expand the services in 2010.

In an urban environment, given time and technical and financial support, the integrated measures would yield higher benefits for better urban environment. Especially, in the big and growing cities like Hyderabad, where the transport sector is increasing many folds, the health benefits of air pollution reduction from this sector will outweigh any other savings.

Acknowledgements

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