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Research Article

Assessment of Particle Number Concentration in Different Transportation Modes along a route in Delhi

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Abstract

A field study was carried out to measure exposure of particle number to commuter on four major commuting modes (in-cabin mode: bus, car and auto rickshaw; on-roadway mode: motorcycle) along a route in Delhi. Recent studies worldwide suggest that number concentration could be a much better predictor and indicator of health effects of particulate than the mass concentration. Portable aerosol spectrometer (GRIMM-Model- 1.108) was used to measure particles concentration twice a day (morning and evening) for 5 weekdays along predetermined route between Kashmere gate and GGSIP University, Dwarka in Delhi region. The results clearly show that the level of exposure was significantly influenced by the commuting mode, showing a higher fine numbers (more than 99%) than coarse (less than 1%) on roadway mode. Higher average concentrations of total PN were observed in motorcycle compared to auto rickshaw, bus and car in morning and in evening the order being bus, motorcycle, auto rickshaw and car respectively. Besides characterizing the various microenvironments in terms of particle number concentration, the results allow the assessment of the individual exposure during commute based on the typical time pattern of people commuting in Delhi. This study has valuable implications that can help commuters to adopt appropriate travel behavior to reduce their personal exposure to such pollutants.

Keywords: *Aerosol; Commuter; Exposure; Commuting modes; Particle number*

1. Introduction

Particulate air pollution has been a longstanding problem in Delhi. Particulate matter (PM) is broadly classified as coarse particles (aerodynamic diameter >2.5 μm), fine particles (aerodynamic diameter between 0.1 and 2.5 μm) and ultra-fine particles (UFP, aerodynamic diameter <0.1 μm) (Pope and Dockery, 2006). The coarse particles have substantial contribution to particle mass but have less contribution to number concentration. Among the major contributors of particulate causing urban air pollution traffic is an important source. Traffic microenvironment has recently received particular attention because $PM_{2.5}$ concentration is often higher than ambient levels on which air quality standard is assessed (Adams *et al.*, 2001; Kam *et al.*, 2011; Cheng *et al.*, 2012a). Most of the air quality studies in India rely on the measurements of suspended particulate matter (SPM) or particles of aerodynamic diameter equal or <10μm (PM_{10}) or $PM_{2.5}$. Air quality standards are confined to $PM_{2.5}$ and PM_{10} fractions and are often mass based. Combustion sources release particles whose size is of submicron range that contribute less to mass concentration. It therefore becomes necessary to obtain inventories for particle number concentration in the above mentioned range.

Recent epidemiological and toxicological studies on particulate matter (PM) pollution focus on health effects associated with the exposure to fine particles, and present evidence of a closer correlation of PM related health hazards with number concentration rather than mass concentration (Donaldson *et al.*, 2002; Peters *et al.* 1997; Wichmann *et al.* 2000). Whereas mass concentration of particle is dominated by larger particles, most of the number of particles is in the ultrafine size range (particle diameter Dp <100 nm), and can reach and deposit in the alveoli region of the lung (Jaques and Kim 2000). Therefore, it has been suggested that particle number concentration could be used to better reflect the adverse health effect of the PM (Seaton *et al*., 1995).

Commuters are exposed to high dosages of air particulates while commuting, but the information on differences in exposure between various modes of transport and routes is very little in terms of quantity. In this study particle number concentrations (PN) in the range of 0.3μm to 22.5μm were monitored using portable aerosol spectrometer, Grimm model 1.108 on five weekdays. The work presented in this paper is intended to provide more comprehensive information about temporal variations of atmospheric particle numbers (PNs) to

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commuter's along a route in Delhi. Because most of the travelling occurs during peak hours, transport-related air pollution contributes significantly to total exposure while commuting.

2. Materials and Methods

The study was conducted in megacity Delhi. The automobile used were motorcycle, auto rickshaw, car and bus (non air- conditioned) along two predetermined routes between Kashmere gate and GGSIP University, Dwarka in Delhi region. The bus and auto rickshaw used for monitoring were operating on Compresses Natural Gas (CNG) fuel. The designated car was a four-stroke Swift Dzire petrol car and the motorcycle was four stroke self-start bikes running on petrol. For this study a GRIMM 1.108 aerosol spectrometer, a portable optical particle counter, was used to measure particulate number concentrations in various transportation modes in the range of 0.3µm and 22.5µm. This instrument is light weighed, easy to handle and operates effectively for a given time resolution. The GRIMM aerosol spectrometer uses light scattering technology to calculate number of particles per unit volume of air. The instrument delivers single particle counts and size classifications in real time.

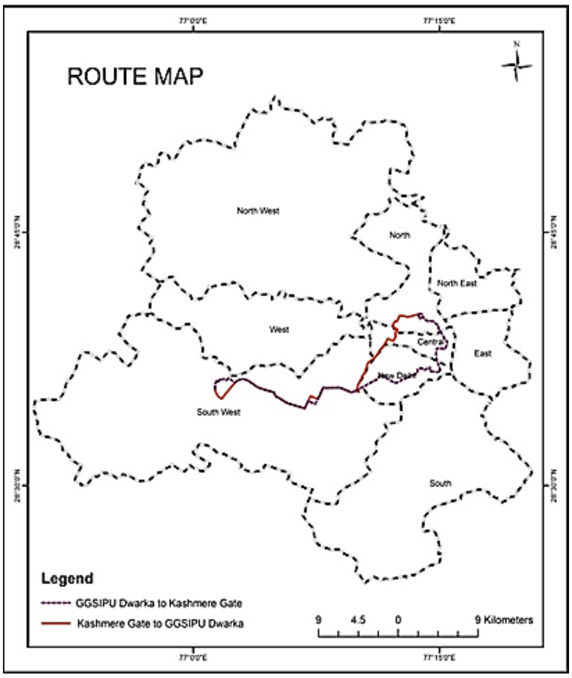


Fig. 1 Description of the sampling route selected for the commuter's exposure study in Delhi, 2012

The device was placed in the rear left seat close to a window in a car, along the side of a window in bus, was close to window in auto rickshaw and in front of person while travelling by motorcycle. The windows were open to know the effect of exposure through air entering the vehicle. The total length of the route was 32-37 Kms and was same for car, bus, auto rickshaw and motorcycle. The preselected route included various types of roads and several signal lights. The in-vehicle particulate number concentrations were measured on five weekdays from February 2012 to march 2012, in various transportation modes. Bus was used from 13th Feb to 17th Feb, 2012, motorcycle from 27th Feb to 2nd March, 2012, auto-rickshaw in the March from 12th to 16th march, 2012 and finally the car from 19th to 23rd march, 2012 respectively. The measurements were taken 2 times a day: morning (08:15-09:30 am) and evening (06:00-07:15 pm) for five working days in Feb-March, 2012. This period was selected as most of the persons are leaving for office at the selected time. No chasing experiment was performed. Grimm Dust monitor conducted real-time particulate number concentrations calculations at every 1 second interval and provided output as 1-minute averages. The data from the instrument were frequently downloaded to a laptop and saved in MS excel format. The characteristics of the two commuting routes were quite constant throughout this study and the average maximum and minimum mean temperature was 23^{0}C and 16^{0}C in the February and it was 28^{0}C and 22^{0}C respectively in the March. GIS-Software Arc info 2011 has been used for preparing sampling route and is shown in figure 1.

3. Results and Discussions

3.1 Particulates Exposure levels in various transport modes

The studies comparing levels of air pollution in various transport modes are limited (Zuurbier *et al*., 2010). Therefore with the aim of determining the differences in commuters' exposure to particle number (PN) concentrations, the monitoring was done on four modes during the month of February and March 2012. The weather conditions were relatively similar during the entire monitoring period of study. Spatio-temporal variability of weekday average of urban fine and coarse particles with time is shown in figure 2.

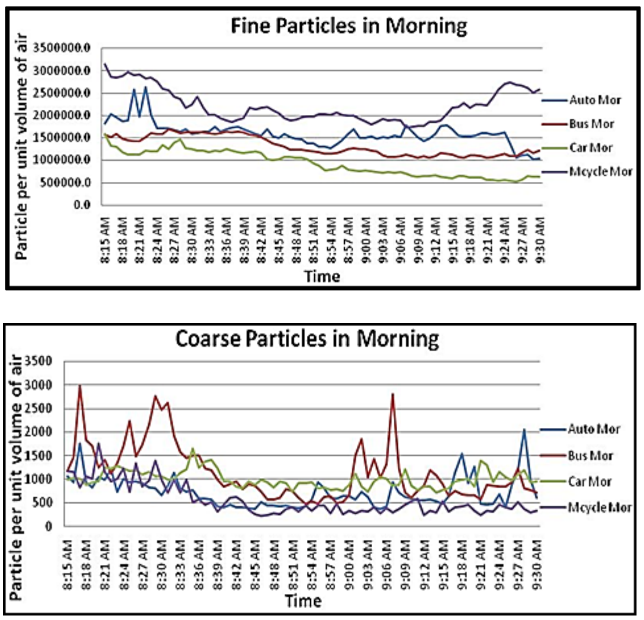


Table 1 Statistical summary of measurements along route covered using auto rickshaw and bus mode in Delhi, India.

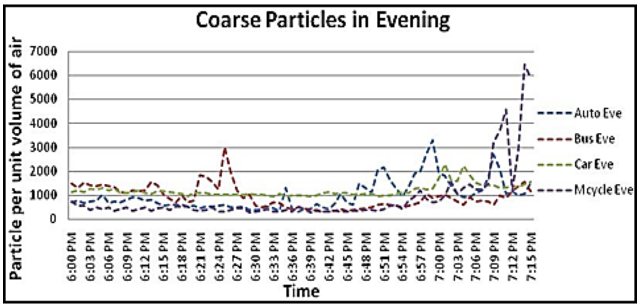
Size (μm)	Unit	IP Kashmere Gate to IP Dwarka		IP Dwarka to IP Kashmere Gate	
		Auto rickshaw	Bus	Auto rickshaw	Bus
		Mean ± SD (Morning)		Mean ± SD (Evening)	
0.35	particle/lit	1091738±188884.8	941889.9±143627.4	321724.2±108140.6	444028.6±68626.7
0.45	particle/lit	316839.8±53270.2	246759.1±41422.4	71128.0±20165.1	134119.8±17630.8
0.575	particle/lit	123614.3±20532.4	85770.2±18871.4	26377.2±6624.8	46539.4±7649.4
0.725	particle/lit	30161.1±5330.7	20544.0±4903.8	8392.2±2073.0	12037.3±2299.4
0.9	particle/lit	13920.9±2312.4	10142.6±2767.3	5667.9±1323.4	6957.3±1906.8
1.3	particle/lit	6690.3±990.3	5693.9±2005.6	3937.2±971.9	4422.1±1553.4
1.8	particle/lit	4448.7±835.2	4728.9±2172.8	3771.1±1238.1	3969.6±1805.6
2.5	particle/lit	3080.0±843.6	4008.6±2073.3	3297.0±1424.5	3235.1±1673.7
3.5	particle/lit	362.7±153.9	581.7±313.4	486.2±284.3	464.7±241.9
4.5	particle/lit	195.9±91.6	320.8±168.6	275.9±176.2	259.2±136.4
6.25	particle/lit	118.4±61.9	190.1±95.3	168.6±114.8	159.8±80.9
8.75	particle/lit	26.6±12.2	36.6±19.1	36.6±24.3	32.1±15.8
12.5	particle/lit	14.5±10.3	12.4±8.9	18.6±11.1	12.0±7.1
17.5	particle/lit	3.5±3.5	2.1±2.0	4.2±2.5	1.9±1.4
22.5	particle/lit	1.7±2.6	0.8±1.4	1.6±1.1	0.6±0.6

Table 2 Statistical summary of measurements along route covered using car and motorcycle mode in Delhi, India.

Size (μm)	Unit	IP Kashmere Gate to IP Dwarka		IP Dwarka to IP Kashmere Gate	
		Car	Motorcycle	Car	Motorcycle
		Mean ± SD (Morning)		Mean ± SD (Evening)	
0.350	particle/lit	633986.1±200105.8	1579699.3±257543.2	241852.4±101074.0	354926.5±143220.9
0.450	particle/lit	175502.6±62171.2	420308.9±68624.6	56345.4±21736.4	77837.3±29225.1
0.575	particle/lit	62861.2±13838.2	156405.5±27771.6	31557.5±7112.6	29205.3±10808.9
0.725	particle/lit	18758.8±2331.0	38267.7±7074.8	13911.9±1832.9	8887.6±3565.3
0.900	particle/lit	12620.6±934.2	15765.1±3042.9	12178.6±1061.4	5394.7±2811.7
1.300	particle/lit	8491.3±528.7	6107.8±1111.1	9446.5±665.1	3421.1±2045.3
1.800	particle/lit	7624.8±574.2	3516.6±988.1	9573.4±681.1	3195.6±2667.5
2.500	particle/lit	5553.6±562.4	2437.2±955.2	7290.9±664.1	2833.0±2823.6
3.500	particle/lit	557.0±91.2	283.6±162.8	697.6±118.9	424.3±547.3
4.500	particle/lit	272.6±53.1	147.1±91.3	319.2±75.3	243.5±342.1
6.250	particle/lit	139.9±33.5	86.9±59.1	147.1±48.5	146.6±218.9
8.750	particle/lit	24.1±6.9	20.5±14.5	21.5±9.8	30.0±40.7
12.500	particle/lit	9.1±3.4	11.1±8.9	7.4±5.2	13.1±15.8
17.500	particle/lit	1.7±1.1	2.8±2.7	1.3±1.1	2.7±3.7
22.500	particle/lit	0.6±0.5	1.2±1.4	0.3±0.4	0.9±1.2

Table 3 Trip averaged counts of fine and coarse particles in four commuting modes in New Delhi, 2012.

Particle Counts	Commuting mode	Trip averaged particles per unit volume of air		N (trip)	Trip duration (minutes)	Percentage (%)	
		Morning	Evening			Morning	Evening
Fine particles (0.350 to 2.5μm)	Auto rickshaw	1590493	444294.8	5	75±10	99.95	99.78
	Bus	1319537.2	655309.2	5	75±10	99.91	99.86
	Car	925399	382156.6	5	75±10	99.89	99.69
	Motorcycle	2222508.1	485701.1	5	75±10	99.98	99.82
Coarse particles (3.50 to 22.5μm)	Auto rickshaw	723.3	991.7	5	75±10	0.05	0.22
	Bus	1144.5	930.3	5	75±10	0.09	0.14
	Car	1005	1194.4	5	75±10	0.11	0.31
	Motorcycle	553.2	861.1	5	75±10	0.02	0.18



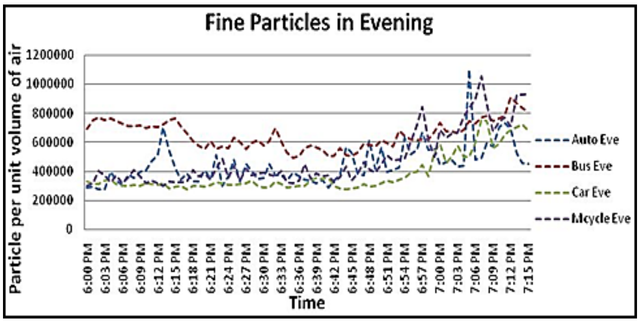


Fig. 2 Spatio-temporal variability of weekday average of urban fine and coarse particles with time

Figure 2 shows that the maximum concentration of fine particles were obtained during the early start of monitoring trip, when vehicle starts its run and it has gradually decreased during the later course of time. The concentration at the end of trip is more than in between the monitoring period.

Statistical summary of measurements along route covered using various transportation modes in Delhi has been given in the table 1 and 2.

From the tables, it is clear that as the size of particles has increased there is simultaneous decrease in the number of particle counts. From the trends obtained above it is clearly understood that particulate number concentrations are mainly influenced by size.

3.2 Differences in exposure between modes of transport

Trip-averaged concentrations were determined for two fractions, averaging for fine (0.3 to 2.5μm) and coarse (3.5 to 22.5μm) respectively. Table 3 summarizes the results of the trip average counts of fine and coarse particles in four commuting modes used in New Delhi.

The percentage contribution of fine particles in morning was maximum in case of motorcycle (99.98%) followed by auto rickshaw (99.95%), bus (99.91%) and car (99.89%) and during evening bus (99.86%) followed by motorcycle (99.82%), auto rickshaw (99.78%) and car (99.69%) respectively.

While for coarse particles the highest exposure was in case of car (0.11%) followed by bus (0.09%), auto rickshaw (0.05%) and motorcycle (0.02%) in morning and car (0.31%), auto rickshaw (0.22%), motorcycle (0.18%) and bus (0.14%) during evening respectively. The particulate results showed obvious patterns with high concentrations in start & end and low during mid time, especially high concentrations of fine particle number concentrations during the morning. From the results it is clearly understood that particulate number concentrations are also influenced by time (peak hours), vehicular traffic, and passengers travelling. A key finding was that particle number (PN) concentrations vary significantly from commuting modes and the concentrations were higher in the morning than in evening.

3.3 Dosages of air pollutants Inhaled

Doses of inhaled pollution were highest for motorcycle, because of the higher minute ventilation. Almost two times higher pollution doses were observed in motorcycle for particle number concentrations. Among the commuting modes chosen for the study the commuter's of motorcycle are closer to traffic emissions more as compared with other modes of transport. Also they are very close to vehicle tailpipes and are often surrounded by other modes of transport on the road. A shorter time interval may demonstrate more rapid changes in particulate levels related to distance from a source. Inhaled air pollutants doses are also influenced by travelling time. Since Delhi's traffic is chaotic and congested with low average speeds, frequent stops at traffic intersections and long idling times so, speed of the test vehicle in this study was not significantly associated either PM levels (Lee *et al*., 2010). We did not take this into account in our study. This was not consistent with other pollutant changes in some other studies.

4. Conclusions

This study provides valuable information on exposure levels of particulate number concentrations to commuter's of an urban area. The data were analyzed to investigate temporal variation, and correlation using MS-excel in order to gain more understanding on their variability and interrelations. It was found that the particulates in the size range of 0.3-2.5 μm contributed to more than 99 %. From the results it is clearly understood that emission of particulates mostly consists of fine particles. Some studies indicate that finer PM has the strongest health effects (Schwartz *et al.*, 1996; Borja- Aburto *et al.*, 1998). It was seen that concentration of particulates in motorcycle was more when compared to other modes concentration. This study displays that exposure to air pollutants is significantly less in case of car than in bus and auto rickshaw. Diurnal graphs indicate that higher particulate concentrations were noted during the morning trips. From trip averaged concentrations it was obtained that maximum concentrations of coarse particle number were found in bus, car and auto rickshaw because of limited air exchange rate within their compartment.

Exposure levels in transport are influenced by the mode and the route and the type of vehicle (Zuurbier *et al*., 2010). Commuter exposure, or in other words, protection against outdoor pollutants, depends on several parameters such as traffic mix and density, type and age of the vehicle, efficiency of particle filter, and the vehicle's operating ventilation settings. The importance is also highlighted by the fact that people can spend a long time in this microenvironment (including commuting in motor vehicles and on bicycle, walking along and waiting on busy street). Exposure to short, high peaks while commuting though motorcycle could be important instead of the lower, longer peaks in cars and buses though they are not clear. This study concluded that reduced exposure to ambient fine-particulate air pollution can result in significant improvement in life expectancy. However, the database is limited in terms of both number of studies, number of subjects and geographical restrictions to allow clear conclusion on the mode of action or generalization of other settings. Therefore further studies need to be initiated to improve our understanding of fine particles and health concerns.

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