Exposure of commuters to particulate matter for various modes of commuting in the Delhi-National Capital Region (NCR)

Bharat Upadhyay¹ and N.C. Gupta¹*

¹University School of Environment Management, Guru Gobind Singh Indraprastha University, Dwarka, New Delhi 110 078, India

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ABSTRACT

In India, traffic is the main cause of air pollution in urban areas. While commuting, commuters are substantially exposed to pollutants. This study was carried out on one of the busiest routes of Delhi – NCR to measure personal exposure to PM₁, PM₁₀, and PM₁₀⁺ in four transportation modes, such as motorcycle, auto-rickshaw, car-open window, and car-AC (Air conditioner). Using a transportable aerosol spectrometer, Particulate Matter (PM) measurements were repeated for five weekdays during peak and off-peak hours for all transportation modes. Trip averaged exposure to pollution to commuters for PM₁ in decreasing order was motorcycle, auto rickshaw, car -open window and car - AC in peak hour and motorcycle, auto rickshaw, car -open window and car - AC in non-peak hour. For PM₁₀, it was motorcycle, auto rickshaw, car- open window and car - AC in peak hour and motorcycle, auto rickshaw, car -open window and car - AC in non-peak hour. Whereas for PM₁₀⁺ it was motorcycle, auto rickshaw, car- open window and car - AC in peak hour and motorcycle, auto rickshaw, car- open window and car -AC in non-peak hour. Size fractions (fine/coarse) varied from 32 to 78% in the peak hour and 24 to 60% in the non-peak hour. The findings of this study can be utilized to focus efforts on lowering personal exposure.

Key words: Air pollution, Aerosol, Commuter exposure, PM₁, PM₁₀, PM₁₀⁺

Introduction

Air pollution in urban areas is an emerging concern nowadays (Kumar et al., 2014). The environmental impact of air pollution has been recognized as a major risk to public health on a global scale (Pant et al., 2016). Vehicle exhaust emissions, industrial pollutants, business activity, brick kilns, thermal plants, road dust, burning of garbage or stubble burning, and other factors can all contribute to air pollution (Singh et al., 2021). Recent estimates indicate that it ranks as the fifth-biggest mortality risk factor (Kolluru and Patra, 2020). According to the Health Effect Institute (HEI, 2019), compared to alcohol consumption and starvation, air pollution is the leading cause of death. According to the World Health Organization (WHO), about 91% of the world’s population is susceptible to and impacted by air pollution (Ma et al., 2020). Worldwide, according to a recent WHO study on the Global Burden of Disease (GBD) states that approx. ~4.2 million premature deaths occur every year due to air pollution (Jain and Barathwal, 2022). Exposure to air pollution affects public health globally and is related to several diseases including cancer, cardiovascular and respiratory illness, pregnancy difficulties, and detri-
ventral birth outcomes (Cepeda et al., 2017). Millions of people die in developing and developed countries, with cities, in particular, having difficulty in meeting the air quality limit values necessary to sufficiently protect human health (Von Schneidemesser et al., 2019).

Particulate matter plays a major role in health risk because of its omnipotent presence among the various air pollutants and has high penetration and deposition power into the lungs. Because of their great penetrability, these particles enter through the mouth as well as the nostrils and are able to travel to the inner lungs, where gas exchange occurs (Kolluru & Patra, 2020). According to studies carried out in six Indian cities including Delhi, Mumbai, Bangalore, Kanpur, Pune, and Chennai published that 30-50% of the ambient particulate matter comes from vehicle exhaust and resuspended road dust. (Kolluru et al., 2018). It is estimated that air pollution causes over two million deaths worldwide each year by harming the lungs and respiratory system. Approximately 2.1 and 0.47 million of these deaths are attributable to fine particulate matter. (PM) and ozone, respectively (Kim et al., 2015).

Over the past two decades, rapid urbanization and industrialization have resulted in an increase in the demand for road transportation to carry people and products. Between, 1990 and 2010, on-road vehicle ownership surged by more than 700%, and by 2030, that number is expected to have multiplied five times (Kolluru et al., 2019). The main contributor to air pollution in urban areas is found to be road transportation (Manojkumar et al., 2021). The complex mixture of particles and gaseous substances that contribute to traffic-related air pollution can directly originate from tailpipe exhaust, resuspension of road dust, tire and brake wear, and secondary aerosols (formed through physical and chemical processes) (Amouei Torkmahalleh et al., 2020). Traffic-related pollutants such as black carbon, particulate matter, nitrogen oxides, volatile organic compounds, and carbon monoxide can have a significant impact on air quality (Shen and Gao, 2019). Air pollution remains a major concern despite recent technical advancements and a decrease in emissions (WHO, 2014) (Schindler et al., 2017).

The amount of pollutants in the air generated by road transportation represents a major public health issue (Apparicio et al., 2018). Due to rising levels of vehicle ownership and an increase in the number of old vehicles, the traffic situation in major Indian cities is getting worse every day (Maji et al., 2021). According to the CPI (Commuter Pain Index), the average commute time of people in India is 1.5 hours per day. Daily commutes considerably increase the degree of pollutant exposure, and any type of physical activity such as speed walking and cycling while commuting, increases the rate at which air is inhaled, increasing the amount of pollutants inhaled (Gokul Raj and Karthikeyan, 2020). Due to their proximity to moving pollutant sources, commuters are exposed to air pollutant concentrations that are higher than those recommended by WHO (Abbass et al., 2021). Commuters appear to be at more risk due to their everyday exposure to air pollution from vehicles (Good et al., 2016). The traffic microenvironment is especially vulnerable to exposure to airborne particulate pollution, because many people spend the majority of their daily time in traffic, which increases the amount they are exposed to air pollution (Qiu et al., 2017). Air contaminants from vehicular exhausts are found in higher amounts near major roads. Commuters who spend more time on or near major roads are expected to have higher daily exposure to traffic-related pollution (Li et al., 2017). Exposure to air pollutant levels in traffic microenvironments are related to parameters such as ambient pollution concentrations, activity and time patterns, transportation mode, atmospheric conditions, traffic load, and route characteristics (Onat et al., 2019). Other factors such as the speed of the wind, speed of the vehicle, vehicle air conditioning (filtration), and vehicle air exchange rate can impact the commuter’s exposure to gases and PM (Amouei Torkmahalleh et al., 2020). According to studies, commuters are exposed to air pollutants in varying amounts depending on their method of transportation, route traveled, and the type of fuel used (Manojkumar et al., 2021).

Personal exposure studies conducted in several microenvironments (work environment, home, transportation, and outdoor) indicated that commuting activity accounts for a major amount of daily exposure (Manojkumar et al., 2021). The objective of this study is to measure on-road exposure to PM (Particulate matter) i.e., $PM_{10}$, $PM_{2.5}$, and $PM_{1}$ in various commuting modes measured using a portable aerosol spectrometer (GRIMM Model no.- 1.108) in 66Km stretch of Delhi-NCR. It works on the principle of light-scattering technology and provides aerosols’ number and mass concentration. It provides data in 15 size channels 0.3, 0.4, 0.5, 0.65, 0.8,
1, 1.6, 2, 3, 4, 5, 7.5, 10, 15, and 20 μm. The commuting modes used in this study include motorcycle, auto-rickshaw, car-window open, and car-AC. As a result, assessing the concentration of commuter exposure is crucial for health effect research and local policymaking.

Materials and Methods

A transportable Aerosol Spectrometer (GRIMM model 1.108) was used to constantly quantify the distribution of particle size of fine particulate material by light scattering, assuming that particles are spherical, and then the PM$_{10}$ and PM$_{2.5}$ mass was estimated from the volume distribution.

Description of the Study Route

The concentrations of airborne particles were monitored between the routes of the two sites, namely Guru Gobind Singh Indraprastha University (GGSIPU), Sector 16 C, Dwarka New Delhi to Gautam Buddha University (GBU) Opp, Yamuna Expy, Greater Noida, Uttar Pradesh. Particulate matter monitoring was carried out from 7th March 2022 to 1st April using a transportable aerosol spectrometer with a temporal resolution of 1 min. of motorcycle, auto rickshaw, car-open window, and car-AC. The peak hour monitoring was done from GGSIPU, New Delhi via Golf course road – Judicial Academy road - Road No. 221 – Sector 6 road - Road No. 201 – Rao Tularam Marg- Mahatma Gandhi road – NH 48 – Baba Banda Singh Bahadur Setu - NH44 – DND flyover - Dabri Main road – Noida Greater Noida Expressway- SurajpurKasna road – GBU, Greater Noida.

The monitoring during non-peak hours started from GBU via SurajpurKasna road - Noida Greater Noida Expressway - Dabri Main road - DND flyover - NH44 - Baba Banda Singh Bahadur Setu - NH 48 - Mahatma Gandhi road - Rao Tularam Marg - Road No. 201 - Sector 6 road - Road No. 221 - Judicial Academy road - Golf course road – GGSIPU, Dwarka, New Delhi – 110078.

A non-smoker measured the exposure twice a day during peak hour and non–peak hour and the same person drove both the motorcycle and the car while the driver was different for an auto-rickshaw. On each sampling day, the monitoring was done from 8:30 to 10:30 a.m. for peak hours and at 11:15 a.m. to 1:15 p.m. for the nonpeak hours. Every sampling day trip started at the same time according to the pre-planned schedules. The monitoring vehicle, an auto-rickshaw, was running on compressed natural gas. The selected car was a four-stroke gasoline-powered Renault Kwid, and the motorcycle that was chosen was a gasoline-powered, four-stroke self-start motorcycle. The monitoring was carried out on the motorcycle mode in March (from 7th to 11th March 2022), on Auto rickshaw (from 14th March to 18th March 2022), on Car – AC in March (from 21st to 25th) and finally in Car – open window (from 28th to 1st April 2022). Throughout the study, the maximum average temperature was 28 °C and 22 °C min mean temperature in March 2022 (Alm et al., 1999) suggested that in order to mitigate the impacts of wind speed, commuters on motorcycles and cars should drive at a speed of about 30 to 40 Km/h. Likewise, auto rickshaw average speeds were also kept between 30 and 40 Km/h. The nature of the two commuting routes was almost identical while the distance of commuting was 66 km (To and fro). ArcGIS 6.10 - GIS software was used to prepare the sampling route maps (Fig. 1). All statistical analyses and descriptive computations were done using SPSS software provided by (GGSIP University, Dwarka, New Delhi).

Results and Discussion

PM Exposure Levels in Different Modes of Transportation

Through the use of the four commuting modes, the level of exposure of twenty trips was monitored from March to April 2022 in one of the busiest routes of Delhi – NCR. The duration of commuting was 120 ± 15 min. for each of the four modes of commuting. The commuter commuting by motorcycle was exposed to maximum PM$_{1.0}$ concentrations (168
µg m⁻³) in the peak hour followed by auto rickshaw, car–open window, and car–AC respectively. Whereas in non-peak hours PM₁₀ exposure was for motorcycle commuters (65 µg m⁻³) followed by auto rickshaw, car–open window and car–AC. Motorcycle commuters were exposed to the maximum concentrations of PM₁₀ of 261 µg m⁻³ in the peak hour followed by auto rickshaw, car–open window and car–AC and in the non–peak hour motorcycle commuters were exposed to 116 µg m⁻³ followed by auto rickshaw, car – open window and car – AC. PM₁₀ data show that the exposure was more to motorcycle 660 µg m⁻³ in the peak hour and 474 µg m⁻³ in the non–peak hour followed by auto rickshaw, car–open window, and car – AC for both peak and non–peak hour.

The last column of Table 1 shows the whole-trip exposure, which was determined by multiplying the commuting concentration by the commuter time per trip. It has been observed that the commuters of motorcycle had the highest whole-trip exposure of PM₁₀ and PM₂₅ while car–AC commuters had the lowest exposure of PM₁₀ as well as for PM₂₅ in the peak hour. The commuters of the motorcycle had the highest whole-trip exposure to PM₁₀ in the peak hour and car–AC commuters had the lowest whole-trip exposure to PM₁₀ in the peak hour. In the non–peak hour motorcycle commuters had the highest whole–trip exposure of PM₁₀ and PM₂₅ while car – AC commuters had the lowest exposure of PM₁₀ as well as for PM₂₅. For PM₁₀ motorcycle commuters had the highest exposure and car – AC commuters had the lowest exposure in the non–peak hour. The size fractions of PM also varied significantly. The fine/coarse (PM₂₅/PM₁₀) ratios were 0.39 for motorcycle, 0.32 for auto rickshaw, 0.43 for car–open window and 0.78 for the car–AC in the peak hour. The ratios for non–peak hour were 0.24 for motorcycle, 0.27 for auto rickshaw, 0.32 for car–open window and 0.6 for car – AC in the non–peak hour. This shows that the size fractions were relatively deviating from the four commuting modes with fine particles (PM₁₀) contributing to 32 to 78% in the peak hour and 24 to 60% in the non–peak hour. The sub-micron/coarse (PM₁/PM₁₀) ratios were 0.25 for motorcycle, 0.21 for auto rickshaw, 0.25 for car–open window and 0.35 for car–AC. Submicron particles (PM₁₀) contributed 21 to 60% in the peak hour and 14 to 35% in the non–peak hour. In the peak hour, the highest ratios were found in the car-AC transportation mode and somewhat similar exposure was observed in the case of car-open window.

Effects of the Events on PM Concentrations (Peak and Non–peak Hours)

We analyzed two events that had an impact on concentrations of vehicular pollution, i.e. peak hour and non–peak hour, to find out whether exposure rose during those events. As demonstrated in Table 1 the concentrations of PM₁₀, PM₂₅, and PM₁₀ substantially decreased from peak hour to non–peak hour for all the commuting modes.

Regression equations are plotted for the relation-

### Table 1. Trip PM Concentrations and whole trip exposure (mean± SD) by four commuting modes in Delhi-NCR, 2022

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Commuting Mode</th>
<th>Trip averaged con.</th>
<th>N (Trip)</th>
<th>Trip duration (min.)</th>
<th>Whole trip exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Peak Hour</td>
<td>Non-peak Hour</td>
<td></td>
<td>Peak Hour</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>Motor cycle</td>
<td>168±78</td>
<td>66±15</td>
<td>5</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>Auto rickshaw</td>
<td>128±67</td>
<td>65±12</td>
<td>5</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>Car-open window</td>
<td>115±30</td>
<td>55±11</td>
<td>5</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>Car - AC</td>
<td>110±42</td>
<td>33±7</td>
<td>5</td>
<td>120</td>
</tr>
<tr>
<td>PM₂₅</td>
<td>Motor cycle</td>
<td>261±132</td>
<td>116±48</td>
<td>5</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>Auto rickshaw</td>
<td>207±117</td>
<td>105±28</td>
<td>5</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>Car-open window</td>
<td>193±109</td>
<td>79±15</td>
<td>5</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>Car - AC</td>
<td>145±41</td>
<td>59±13</td>
<td>5</td>
<td>120</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>Motor cycle</td>
<td>660±315</td>
<td>474±48</td>
<td>5</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>Auto rickshaw</td>
<td>626±295</td>
<td>383±171</td>
<td>5</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>Car-open window</td>
<td>446±221</td>
<td>249±103</td>
<td>5</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>Car - AC</td>
<td>187±63</td>
<td>101±67</td>
<td>5</td>
<td>120</td>
</tr>
</tbody>
</table>
ship between PM$_1$ with PM$_{2.5}$ and PM$_{10}$, as shown in Figure 2 for the peak hour. It is observed from Table 2 and Fig. 2 that for PM$_{2.5}$ car-AC in the peak hour, the values of the coefficient of determination and regression coefficient are 0.9877 and 1.18. This indicates a relationship between PM$_{2.5}$ and PM$_{1.0}$ for car-AC is highly positive. Likewise, from Fig. 3 and Table 2 for PM$_{2.5}$ car-AC in the non-peak hour, the values of the coefficient of determination and regression coefficient are 0.99 and 1.15, so the relation is highly positive. Thus for PM$_{2.5}$ in the peak hour, the coefficients of determinations observed were better for car-AC (0.98) followed by auto-rickshaw (0.94), car-open window (0.89), and motorcycle (0.66); and during non-peak hour period, those are car-AC (0.99), auto-rickshaw (0.88) and similar for motorcycle and car-open window (0.75).

Regression equations are plotted for the relationship between PM$_1$ with PM$_{2.5}$ and PM$_{10}$ as shown in Figure 3 for the non-peak hour. It is observed from Fig. 2 and Table 3 for PM$_{10}$ car-AC in the peak hour, the value of the coefficient of determination and regression coefficient are 0.87 and 1.13, respectively; likewise from Table 3 and Fig. 3 in the non-peak hour, the value of coefficient of determination and regression coefficient are 0.90 and 1.25. This implies the relation of car-AC PM$_{10}$ is highly positive in both peak and non-peak hours. Thus for PM$_{10}$ in the peak hour, the determination coefficient was better for car-AC (0.87) than auto-rickshaw (0.62), car-open window (0.42), and motorcycle (0.18), and during non-peak hour car-AC (0.90), car-open window (0.19), motorcycle (0.04) and auto-rickshaw (0.04).

The commuters’ PM exposure is significantly affected by their mode of commuting. The time of day had the biggest impact on PM concentrations in this study; PM mass concentrations were found to be higher in the peak hour and lower concentrations in the non-peak hour. The greater peak hour exposure is possibly due to greater vehicular traffic during peak hours (Qui et al., 2017). Furthermore, changes in PM concentrations of mass at different times of the day are caused by the atmosphere’s varying levels of stability and instability. The PM mass concentration may be enhanced by higher morning (peak hour) humidity, and wind speed may also be a significant contributing component. According to (Gehrig and Buchmann, 2003), the fine/coarse (PM$_{2.5}$/PM$_{10}$) ratio at about 0.6 demonstrates that mechanically created particles have a significant impact on it. The PM$_{2.5}$/PM$_{10}$ ratios determined from the study were 0.52-0.78 in the peak hour and 0.24-0.60 in the non-peak hour. The ratios determined in the study conducted by (Tsai et al., 2008) were 0.53-0.60 and 0.57 in Taipei by (Li and Lin, 2002). According to (Chow et al., 1994) PM$_{2.5}$ often makes up more than 50% of PM$_{10}$ in the regions of metropolitan areas, which is consistent with the results of the current study. The submicron/coarse ratios were 0.21-0.60 in the peak hour and 0.14-0.35 in the non-peak hour which falls in the range of 0.39-0.45 (Tsai et al., 2008) and 0.22-0.60 (Li and Lin, 2002). A shorter time period may result in more abrupt variations in PM levels as a result of distance from a source. Delhi-

### Table 2. Comparisons of PM$_{2.5}$ with PM$_{1}$ concentrations while commuting between peak and non-peak hours using the regression equation

<table>
<thead>
<tr>
<th>Commuting mode</th>
<th>Peak hour</th>
<th>Non-peak hour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Regression Eq.</td>
<td>r$^2$</td>
</tr>
<tr>
<td>Motorcycle</td>
<td>y=2.0635x-18.036</td>
<td>0.6678</td>
</tr>
<tr>
<td>Auto rickshaw</td>
<td>y=1.2886x+28.391</td>
<td>0.9466</td>
</tr>
<tr>
<td>Car-open window</td>
<td>y=1.441x+18.889</td>
<td>0.8917</td>
</tr>
<tr>
<td>Car-AC</td>
<td>y=1.1809x+8.6501</td>
<td>0.9877</td>
</tr>
</tbody>
</table>

### Table 3. Comparisons of PM$_{10}$ with PM$_{1}$ concentrations while commuting between peak and non-peak hours using the regression equation

<table>
<thead>
<tr>
<th>Commuting mode</th>
<th>Peak hour</th>
<th>Non-peak hour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Regression Eq.</td>
<td>r$^2$</td>
</tr>
<tr>
<td>Motorcycle</td>
<td>y=2.8076x+347.85</td>
<td>0.1801</td>
</tr>
<tr>
<td>Auto rickshaw</td>
<td>y=2.1362x+253.37</td>
<td>0.6209</td>
</tr>
<tr>
<td>Car-open window</td>
<td>y=2.118x+262.73</td>
<td>0.4226</td>
</tr>
<tr>
<td>Car-AC</td>
<td>y=1.1321x+56.954</td>
<td>0.8684</td>
</tr>
</tbody>
</table>
NCR traffic is chaotic, crowded, and moves at slow average speeds, with constant stops at traffic intersections and prolonged idling times. In the present study, the test vehicle speed was not significantly related to either PM concentration. This was distinguished from other pollutant changes observed in earlier studies.

**Conclusion**

Road traffic is a significant contributor to particulate matter pollution in developing countries, where rapid urbanization and poor land use and transportation planning may lead to high levels of harmful fine particulate matter. This study provides vital details on commuter’s PM exposure levels in an urban area. To further comprehend the data’s variability and interrelations, the SPSS tool was used to analyze the data to look at temporal variation and correlation. Commuter’s exposure to PM over a standardized route was monitored frequently. Accord-
ing to commuters PM$_{1.0}$ (µg m$^{-3}$) results, the order of trip average exposure was as follows motorcycle > auto rickshaw > car – open window > car AC during peak hour and motorcycle > auto rickshaw > car – open window > car AC during non–peak hour. For PM$_{2.5}$ (µg m$^{-3}$) the order was as follows motorcycle > auto rickshaw > car – open window > car AC during peak hours and motorcycle > auto rickshaw > car – open window > car AC during non–peak hour. The order for PM$_{10}$ (µg m$^{-3}$) was as follows motorcycle > auto rickshaw > car – open window > car AC during peak hours and motorcycle > auto rickshaw > car – open window > car AC during non–peak hour. Apparently, traffic volume has a high impact on in-vehicle exposures. Temporal characteristics indicate that in vehicle exposure is related to nearby traffic, emphasizing the importance of local sources, most likely vehicular activity. The levels of PM exposure are difficult to generalize, hence it is imperative to conduct further mode-specific research. Therefore, more statistical analysis of the large database may be required to uncover additional factors affecting commuter’s PM exposures.

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**Declarations**

Conflict of interest: The authors declared that there are no competing or conflicting interests.

Ethics Approval: This article does not include any human or animal experiments conducted by the authors.

**Conflict of Interest- None**

**References**


