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Pollutant Emissions from Road Vehicles in Mega-City Kolkata, India: Past and Present Trends

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Abstract

Road vehicles are major sources of air pollutants in urban areas. Their impact on air quality is very large in rapidly growing megacities like Kolkata (India). The aim of this study is to estimate the contribution of road vehicles towards various pollutants (e.g. CO2, CO, NOx, SPM, SO2 and VOCs) in Kolkata between 2000 and 2010. Two scenarios considering phasing out and non-phasing out of vehicles after their serving age are considered. Distinguishable higher emissions were observed in emissions for non-phasing out scenario compared to phasing out scenario. It has been further observed that CO and VOC emissions were dominated by four wheeler petrol vehicles, while other pollutants were dominated by commercial diesel vehicles in both the scenarios. Emission estimates for the year 2010 suggest a large increase in the phasing out scenario considering continuous phasing out of old vehicles and maintaining same growth trends of vehicle population, while during the same year emissions from non-phasing out scenario appear to decrease due to automatic retirement of old vehicles and introduction of advanced technology. The study concludes that external traffic load should be bypassed from the city as it contributes considerably to the city pollution load. Also, the implementation of the phasing out laws for old vehicles should be effectively carried out to control the pollution load due to traffic.

Keywords: Emission inventory, Road transport, Vehicular emissions, megacity Kolkata

Introduction

Transport sector is the major source of air pollution in the metropolitan cities of India (Gurjar et al. 2004). The annual growth rate of motor vehicles in India has been around 10% during the last decade. About 32% of these vehicles are plying in metropolitan cities, which constitute 11% of the total population of vehicles in India (Singh 2005). Leaving aside other mega cities of India, the number of vehicles registered in Kolkata alone was 50,000 or so in 1951 that rose to around 500,000 in 1991 – a ten-fold rise when the population rose by 39% (Dutta 2001). However, the road space (matching with population density) in the Kolkata city is only 6%, compared with 23% in Delhi and 17% in Mumbai, which creates major traffic problems (Dutta 2001), although Kolkata metro railway and a number of new roads and flyovers have decongested traffic to some extent.

Among motorized forms of transport, the city has buses, trams, autos (three wheelers), taxis, metro, circular rail, water-ferries and local trains for public transport. For private transport Kolkata has two wheelers and cars and commercial buses. The state has regular, special and executive fleets of buses. The private buses are categorized as ordinary, chartered, school buses and minibuses. Besides, there are non-motorized forms of road transport like rickshaws and bicycles. The average speed of the vehicles on road at present is 20 km h⁻¹. According to a study
conducted by Centre for Science and Environment (CSE), New Delhi, the quantity of all the three major air pollutants (namely CO, HC, and NO$_x$) drastically increases with a reduction in motor vehicle speeds. For example, at a speed of 75 km h$^{-1}$, measured emission of CO was found to be 6.4 gm veh$^{-1}$ km$^{-1}$, which became 33.0 gm veh$^{-1}$ km$^{-1}$ at a speed of 10 km h$^{-1}$. Similarly, measured emission of hydrocarbons increased by 4.8 times from 0.93 to 4.47 gm per vehicle km$^{-1}$ at the same vehicle speeds (Padam and Singh, 2004).

The aims of this study are to quantify the vehicular emission loads in the mega-city Kolkata for the period 2000-2005 and to estimate the emissions in the year 2010 considering the technological advancements in vehicles. The study also aims to determine the changing trends in the levels of various air pollutants over this period due to the combination of several factors (e.g. rising population, increasing travel demand and introduction of policy and technological interventions). This study will help to identify the potential sources of various pollutants and effects of reforms already introduced to assist policy makers and modelers in developing future control strategies. Once the cause for the rising levels of a particular pollutant is identified, effective measures can be applied in a definite direction to control the pollution loads.

**Methodology**

As suggested and applied by Gurjar et al. (2004), a spreadsheet model based on Eq. (1) that includes emission factor and activity based approach, has been used for calculating vehicular emissions from road transport in Kolkata.

$$E_i = \sum (V_{ij} \times D_j) \times E_{ij \text{ km}}$$

(1)

Where

- $E_i$ = Emission of pollutant (i) per km traveled by a vehicle
- $V_{ij}$ = Number of vehicles of each type (j)
- $D_j$ = Distance travelled in a year by each type of vehicle (j)
- $E_{ij \text{ km}}$ = Emission of pollutant (i) by a vehicle type (j) per km traveled

**Vehicle Population**

The vehicle population for the period of 2000 to 2005 has been estimated for different vehicles using the population data available in Auto Policy Report (Mashelkar et al. 2002). The population for the future years has been calculated by assuming geometric progression through finding the yearly increase rate for different types of vehicles. Further, the study involves emission calculations involving two scenarios i.e. with and without phasing out of vehicles according to the age. The number of newly registered vehicles for each year was found out. Population of two wheeler vehicles was categorized into 2-stroke (2S) and 4 stroke (4S) assuming a ratio of 8:1 for 2S:4S (Biswas 2006); this exercise was performed to study the relative advantage of 4S two-wheelers over 2S two-wheelers. The ratio of cars to taxis was taken according to the percentage as 15.1% of the total number of cars and taxis on road (Mashelkar et al., 2002). The percentage of external vehicles coming to Kolkata daily was calculated from the available 2002 data (Mashelkar et al. 2002); this data was projected for future years to estimate the external population of vehicles and applied to correct the data.

The age-wise distribution of the vehicle population in Kolkata was also taken from Auto Fuel Policy Report that was based on the fuel station surveys conducted in 2002 (Mashelkar et al. 2002). This distribution was assumed to be constant for the period 2001–2005. The average age of different vehicles was taken from the study of (Mittal and Sharma 2003). The vehicle utilization factors (km traveled per day per vehicle type) were adapted from the fuel station surveys reported in Auto Fuel Policy Report (Table 1).
Table 1: Utilization Factors for Different Types of Vehicle

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>km/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars/Jeeps</td>
<td>52.6</td>
</tr>
<tr>
<td>Taxis</td>
<td>77.89</td>
</tr>
<tr>
<td>2 Wheelers</td>
<td>25.1</td>
</tr>
<tr>
<td>Auto</td>
<td>97.72</td>
</tr>
<tr>
<td>Buses</td>
<td>80.2</td>
</tr>
<tr>
<td>LCV</td>
<td>45.5</td>
</tr>
<tr>
<td>HCV</td>
<td>45.5</td>
</tr>
</tbody>
</table>

Note: Auto=Three wheelers; LCV=Light commercial vehicle; HCV=Heavy commercial vehicle

Emission Factors

It was hard to find the emission factors for Kolkata vehicles for a range of pollutants (CO, CO\textsubscript{2}, NO\textsubscript{x}, SPM, SO\textsubscript{2}, VOC) considering driving conditions and control measures. Earlier studies, e.g., Das and Parikh (2004) and Jalihal and Reddy (2006), have simply taken the norms introduced by CPCB as emission factors, but such calculations underestimate the emissions as the actual driving condition on Kolkata roads are not as ideal as considered in the norms. Therefore, to make realistic estimates, we compiled the emission factors for different types of vehicles and pollutants from a range of sources that consider several factors such as condition of the road, load on vehicles, acceleration, speed cycle, and maintenance of vehicles. A detailed comprehensive list is given in Table 2.

Further, deterioration factors (related to age of vehicles) were applied to correct the emission factors for different age categories of vehicles (Mashelkar et al. 2002). The emission loads for a particular pollutant were computed through Eq. (1) that uses the product of vehicle utilization factors with number of vehicles in each age-group category and corresponding emission factors for that category.

Two Scenarios

Pollution estimations were carried out in two scenarios (i.e. with and without implementing the phasing out rules of the vehicles). In each case, the population of different types of vehicles varies. Emission factors that are to be multiplied with the population of vehicles over a certain period have been selected as given in Table 2. Total emissions (in Gg/yr) over a particular period have been thus estimated by considering the above two factors.

Table 2: Emission Factors for the Various Vehicle Types Used for Emission Estimations

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Year</th>
<th>CO\textsubscript{2}</th>
<th>CO</th>
<th>SO\textsubscript{2}</th>
<th>NO\textsubscript{x}</th>
<th>SPM</th>
<th>VOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>2W2S</td>
<td>Pre 1995</td>
<td>26.6\textsuperscript{d}</td>
<td>8.3\textsuperscript{e}</td>
<td>0.05\textsuperscript{cf}</td>
<td>0.7\textsuperscript{n}</td>
<td>0.5\textsuperscript{c,ef}</td>
<td>5 \textsuperscript{c,ef}</td>
</tr>
<tr>
<td></td>
<td>1990-2000</td>
<td>26.6\textsuperscript{d}</td>
<td>5\textsuperscript{f}</td>
<td>0.05\textsuperscript{c,ef}</td>
<td>0.1\textsuperscript{ac}</td>
<td>0.5\textsuperscript{c,ef}</td>
<td>5 \textsuperscript{c,ef}</td>
</tr>
<tr>
<td></td>
<td>2001-05</td>
<td>26.6\textsuperscript{d}</td>
<td>2.4\textsuperscript{e}</td>
<td>0.05\textsuperscript{c,ef}</td>
<td>0.1\textsuperscript{ac}</td>
<td>0.5\textsuperscript{c,ef}</td>
<td>5 \textsuperscript{c,ef}</td>
</tr>
<tr>
<td></td>
<td>2006-10</td>
<td>26.6\textsuperscript{d}</td>
<td>1.4\textsuperscript{b}</td>
<td>0.05\textsuperscript{c,ef}</td>
<td>0.07\textsuperscript{b}</td>
<td>0.05\textsuperscript{b}</td>
<td>5 \textsuperscript{c,ef}</td>
</tr>
<tr>
<td>2W4S</td>
<td>Pre 1995</td>
<td>28.3\textsuperscript{d}</td>
<td>6.49\textsuperscript{a}</td>
<td>0.03\textsuperscript{c,ef}</td>
<td>0.7\textsuperscript{n}</td>
<td>0.08\textsuperscript{c}</td>
<td>0.72 \textsuperscript{c}</td>
</tr>
<tr>
<td></td>
<td>1996-2000</td>
<td>28.3\textsuperscript{d}</td>
<td>2.6\textsuperscript{b}</td>
<td>0.03\textsuperscript{c,ef}</td>
<td>0.39\textsuperscript{f}</td>
<td>0.08\textsuperscript{c}</td>
<td>0.72 \textsuperscript{c}</td>
</tr>
<tr>
<td></td>
<td>2001-05</td>
<td>28.3\textsuperscript{d}</td>
<td>2.2\textsuperscript{b}</td>
<td>0.03\textsuperscript{c,ef}</td>
<td>0.39\textsuperscript{f}</td>
<td>0.08\textsuperscript{c}</td>
<td>0.72 \textsuperscript{c}</td>
</tr>
<tr>
<td></td>
<td>2006-10</td>
<td>28.3\textsuperscript{d}</td>
<td>2.4\textsuperscript{b}</td>
<td>0.03\textsuperscript{c,ef}</td>
<td>0.3\textsuperscript{b}</td>
<td>0.05\textsuperscript{b}</td>
<td>0.05 \textsuperscript{b}</td>
</tr>
<tr>
<td>3W</td>
<td>Pre 1995</td>
<td>60.3\textsuperscript{d}</td>
<td>14\textsuperscript{b}</td>
<td>0.1\textsuperscript{ef}</td>
<td>0.1\textsuperscript{ef}</td>
<td>0.5\textsuperscript{ef}</td>
<td>8 \textsuperscript{ef}</td>
</tr>
<tr>
<td></td>
<td>1996-2000</td>
<td>60.3\textsuperscript{d}</td>
<td>12.25\textsuperscript{e}</td>
<td>0.1\textsuperscript{ef}</td>
<td>0.1\textsuperscript{ef}</td>
<td>0.5\textsuperscript{ef}</td>
<td>8 \textsuperscript{ef}</td>
</tr>
<tr>
<td></td>
<td>2001-05</td>
<td>60.3\textsuperscript{d}</td>
<td>5.2\textsuperscript{ef}</td>
<td>0.1\textsuperscript{ef}</td>
<td>0.26\textsuperscript{ef}</td>
<td>0.5\textsuperscript{ef}</td>
<td>8 \textsuperscript{ef}</td>
</tr>
<tr>
<td></td>
<td>2006-10</td>
<td>60.3\textsuperscript{d}</td>
<td>2.45\textsuperscript{b}</td>
<td>0.12\textsuperscript{b}</td>
<td>0.08\textsuperscript{b}</td>
<td>0.08\textsuperscript{b}</td>
<td></td>
</tr>
<tr>
<td>Year</td>
<td>4WG</td>
<td>4WD</td>
<td>Bus / Truck</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>--------------</td>
<td>-------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre 1995</td>
<td>223.6</td>
<td>12.7</td>
<td>515.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1996-2000</td>
<td>223.6</td>
<td>7.3</td>
<td>515.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2001-05</td>
<td>223.6</td>
<td>2.6</td>
<td>515.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006-10</td>
<td>223.6</td>
<td>1.3</td>
<td>515.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results and Discussions

Figures 1 to 6 show total emissions of CO₂, CO, SO₂, NOx, SPM and VOCs, respectively for phasing out and non-phasing out periods between 2000 and 2010. As expected, results show a considerable lower emissions in phasing out scenario compared to non-phasing out scenario. Pollutants specific discussion is presented in the subsequent sections.

CO₂ Emissions

The emission trends of non-phasing out scenario for CO₂ emission shows an increase from 4586 Gg in 2000 to 5590 Gg in 2005 (Figure 1a). This increase is in accordance to the increase in the registered number of vehicles in each year. However strangely enough, estimated emissions for the year 2010 are less (4513 Gg) than that for the year 2005. This may be due to the introduction of advanced technology for the ever increasing registered new vehicles and the automatic retirement of old vehicles. Estimated emissions in the phasing out scenario for the period between 2000 and 2005 although are lower in magnitude compared to the non-phasing scenario, but still show an increase from 2763 to 3570 Gg during this period, a trend that has been observed even for the year 2010 (Figure 1b).

Contribution of different vehicle types towards CO₂ emissions has shown almost the same percentage in both the phasing out and non-phasing out scenarios during the period 2000–2005 (Figure 1a, b). In both scenarios, contribution of HCVs is the highest (36–40% of total CO₂) among all vehicle categories, followed by the cars (26–27%). Two wheelers and three wheelers contribute the least among all vehicle categories. Interestingly slight differences were observed in contributions of buses in phasing out (17%) and non-phasing out (14%) scenarios.
CO Emissions show an increasing trend in the non-phasing out scenario from 239 Gg in 2000 to 257 Gg in 2005 (Figure 2a). Emissions declined from 2005 to 2010 because of phasing out of 25 year old vehicles and consideration of lower emission factors due to technological advancement (Figure 2a). The phasing out scenario also shows an increase in CO emissions between 2000 and 2005 (124 to 127 Gg). This may be mainly due to the increase in the number of new vehicles. A decrease in the emission rate was seen in the year 2010 (111Gg) (see Figure 2b). As expected, emissions are in general less in the phasing out scenario as compared to those in the non-phasing out scenario because of regular shunting process of the vehicles from the road by local authorities.

The percentage contribution of different vehicle types to total CO emissions during the years 2000 to 2005 are nearly similar in both the scenarios. However total emissions from phasing out scenario were 45-51% less than in the non-phasing out scenario. Cars contribute highest CO emissions in both phasing out (41–48%) and non–phasing out (47–50%) scenarios during 2000-2005. HCVs are the second largest contributor in both phasing out (15–18%) and non–phasing out (16–18%) scenarios, followed by three wheelers (12–15% and 08-10% in phasing and non–phasing out scenarios, respectively) and 2S two wheelers (10-11% and 11% in phasing and non–phasing out scenarios, respectively.)
Figure 2: CO Emissions in (a) Non–phasing out, and (b) Phasing out Scenarios

SO$_2$ Emissions
As seen in Figure 3a, SO$_2$ emission in the non–phasing out scenario shows a similar trend as that of CO emissions. Emissions of SO$_2$ increased from 31 Gg in 2000 to 34 Gg in 2005, but reduced further to about 21 Gg in the year 2010. Reasons identical to CO emissions for the observed trend have been found in the case of SO$_2$ (see Section 3.2). Similar emission trends in the case of non-phasing scenario have been noticed i.e., a steady increase until 2005, with a slight decrease in the year 2010 (Figure 3). Approximately 19 Gg of SO$_2$ emissions were estimated in the year 2000 in case of phasing out scenario which increased to 21 Gg in 2005, but reduced to about 20 Gg in 2010 (Figure 3b).

Among all the vehicle categories, HCVs accounted to about 54 to 58% of SO$_2$ emissions in both scenarios, followed by buses in phasing out (24–25%) and non–phasing (20–21%) out scenarios. LCV is observed as the next largest contributor, followed by taxis and cars. The contribution from the two wheelers and three wheelers are the lowest in both the scenarios (Figure 3).
Continuous increase in NO$_x$ emissions was observed in non-phasing out scenario until 2005 (137 Gg in 2000 and 157 Gg in 2005), followed by a decrease of about 48% from 2005 to 2010 (Figure 4a). The probable reason might be the retirement of old age vehicles and introduction of reduced emission factors based on new engine technology. Similar trend has been noticed for phasing out scenario. Emission of NO$_x$ has increased from 83 Gg in 2000 to 101 Gg in 2005 with a decrease of 21% from 2005 to 2010 (Figure 4). The decreasing trend between 2005 and 2010 in both the scenarios may be presumably due to the low emissions factors during this period.

HCVs were found to be the largest contributor of NO$_x$ (53 to 54%) emissions in both phasing out and non-phasing out scenario (Figure 4). After HCVs, buses emerged as the second largest contributor in phasing out (22-25%) and non-phasing out (19-21%) scenarios. This is followed by LCVs and cars. The contribution of NO$_x$ emissions from cars were noticed to be decreasing from 12% in 2000 to about 8% in 2005 in phasing out scenario as opposed to only 1% changes in non-phasing out scenario (Figure 4).
Suspended Particulate Matter (SPM) Emissions

SLP emissions also increased from 11 Gg in 2000 to 14 Gg in 2005 and declined by about 37% thereafter (9 Gg) in 2010. This is basically due to exclusion of old vehicles (i.e., registered before 1985) and the lower emission factor norms used between 2005 and 2010 (Figure 5a). SPM emissions were less in phasing out scenario compared to non-phasing out scenario. This is influenced by the lesser number of vehicles considered for calculations and the substantially reduced emission factors for the various periods in the phasing out scenario (Figure 5b).

HCVs seem to dominate the SPM emissions in both phasing and non-phasing out scenarios with their contribution decreasing from 36% in 2000 to 33% in 2005 followed by two wheelers (15–16% and 16–18%) and buses (15–16% and 12–13%) in both the phasing and non-phasing out scenarios respectively (Figure 5).
VOC Emissions showed a continuously increasing trend between 2000 and 2010 in the non-phasing out scenario, with the rate of increase relatively small during the period 2005-2010 (Figure 6a). Similar trend was noticed in the phasing out scenario, but the rate of increase was almost the same for both 2000-2005 and 2005-2010 periods (Figure 6b).

Contribution of three wheelers towards VOC emissions was the largest (23–32%) in phasing out scenario while car emissions dominated (31–35%) the non-phasing out scenario. The contribution of cars decreased over the period 2000–2005, but the contribution of three wheelers kept on increasing in both the scenarios (Figure 6a, b). Interestingly, contribution of two wheelers remained almost the same in both the scenarios.

Figure 5: SPM emissions in (a) non–phasing out, and (b) phasing out scenarios.
Comparison of Measured and Estimated Emissions to Assess Air Quality Trends

Figure 7 shows annual changes in measured SO₂, NOₓ, and SPM concentrations in ambient air in Kolkata between 2000 and 2005; this data has been taken from the Central Pollution Control Board, New Delhi. Note that the data presented in Figure 7 shows ambient concentrations (µg m⁻³) taken on two residential and one industrial site whereas we have estimated total annual emissions (Gg) from all road vehicles. However, Figure 7 provides us an opportunity to compare the overall trend of measured emissions with our estimates during the previous years. Drastic decrease has been noticed in the concentrations of SPM between 2000 and 2001; thereafter a continuous increase was noticed till 2005. This trend of measured concentrations was somewhat followed by estimated SPM emissions for both phasing out and non-phasing out scenarios (Figure 5).

Ambient air concentration of NOₓ increased substantially between 2000 and 2001 whereas a decreasing trend was observed after 2002. This trend is just opposite to our estimated emission trend. Possible reasons could be: i) the contribution of various other sources (e.g. industrial and domestic emissions) to NOₓ emissions that are not included in our emission estimates, and ii) role of meteorology and atmospheric chemistry (since NOₓ is a precursor of Ozone and secondary aerosols), which are beyond the scope of the present study.

The SO₂ concentrations shown in Figure 7 are nearly identical in different years as opposed to our estimates showing a small but continuous increase until 2005. An important reason behind this dissimilarity could be that the data presented in Figure 7 is site specific (includes only three sites i.e. two residential and one industrial) whereas our estimates provides actual conditions of transportation emission over the entire city.
Figure 7: Air Quality Trends in Kolkata during 2000-2005. The Measured Data have been taken from Central Pollution Control Board, New Delhi.

Limitations & Further Scope of the Study
Our methodology accompanied a number of limitations due to non-availability of detailed vehicle population and emission factor data. Vehicle population data was available only for the year 2002, so the vehicle population for the rest of the years has been projected based on geometric progression. Furthermore, the percentage of external population was available only for the year 2002 and we assumed it constant for the rest of the years. The category wise data for 2S and 4S two wheelers was not available and the division was done assuming a ratio specified by (Biswas 2006). The vehicle utilization factors were also assumed to be constant for the five year period ignoring the rising travel demand in the country. Besides this, selection of emission factors from a range of different sources can also generate uncertainty in calculations. Some of the values were adapted from the norms in the absence of any other source which would be an underestimation of the condition that actually exists on Kolkata roads. Nevertheless, the assumptions used for emission estimates are substantiated by published literature, providing a realistic chance for such estimates despite odd availability of required data.

Conclusion
Emissions of all the considered pollutants, except VOCs and CO, from vehicles in Kolkata were mainly from the high population of the commercial goods vehicles and the buses, though the contribution of the cars and taxis was also considerable. Since commercial vehicles and buses contribute considerable pollutant emissions, it points out the need for bypassing of external traffic that currently passes through Kolkata. The ever increasing demand of personal vehicles also contributes substantially towards emissions of CO, VOCs and other pollutants. Thus, there is a need to improve the mass transit system in the city. As the contribution of diesel buses is quite large, introduction of CNG mass transit in the megacity could be considered. Our results also show that the estimated emissions for all the pollutants are much higher for the non-phasing out scenario of vehicles. Therefore, the government of West Bengal should consider introducing effective laws for phasing out the vehicles and an arrangement to make sure that these laws are
implemented. Given that the development of Kolkata keeps on continuously increasing, there is a great potential in the increase of vehicle population in future. This can subsequently lead to increased level of pollutant emissions and associated health problems. Therefore, focused efforts are needed to implement various norms and laws in the stringent manner besides creating awareness in the general public.

Acknowledgments
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