Horizontal gradients of traffic related air pollutants near a major highway in Agra, India

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In the present study, horizontal gradients of airborne particles and gases were observed perpendicular to the national highway (NH-2) in Agra, India. A negative association was found between distance (from the highway) and ambient concentrations of pollutants. Gradients suggest that the major impact of traffic flow on the pollutants concentration lies within 250 m distance. Over the total measured distance (0-500 m), the maximum percent decrease in concentrations was observed for total suspended particulate matter (TSPM), particulate matter with aerodynamic diameter less than 10 µm (PM\(_{10}\)), sulphur dioxide (SO\(_2\)), nitrogen dioxide (NO\(_2\)), ozone (O\(_3\)) and carbon monoxide (CO) within 0-250 m distance range. However, no significant decrease in concentrations of carbon dioxide (CO\(_2\)) was obtained. Correlations between all of the pollutants considered in this study are positive with many of them being highly correlated and significant, which shows that their sources are almost similar. On comparing the pollutants concentrations with available standards of Central Pollution Control Board (CPCB), SO\(_2\), CO, NO\(_x\) and O\(_3\) concentrations were found within the permissible limits, whereas PM\(_{10}\) concentration was found higher. This study generates data which can be useful for Asian city planners for planning residential colonies so as to cause minimum exposure to the residents.

Keywords: Horizontal gradient, Air pollutants, Pollutant concentration, Traffic exhaust pollutants

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1 Introduction

In Asian cities where high levels of human activities in and around transport corridors are common place, the incidence of people having health problems is very high\(^1\). Vehicles in major cities of India are estimated to account for 70% of the respective total pollution loads\(^3\). Motor vehicle engines emit various types of pollutants including nitrogen oxides (NO\(_x\)), carbon monoxide (CO), carbon dioxide (CO\(_2\)), particulates, sulphur dioxide (SO\(_2\)). Most of the primary vehicle emitted pollutants are transformed in the atmosphere to other secondary pollutants like ozone (O\(_3\)). Ozone is an irritant and can cause inflammatory reaction on inhalation\(^3\). In the presence of volatile organic compounds (VOC’s), CO and nitrogen oxides (NO + NO\(_2\) = NO\(_x\)), ozone is photo chemically produced and can accumulate hazardous levels in favourable weather conditions\(^4,5\). Hyper concentration of pollutants takes place mainly on the national highways and major connecting roads of the cities where vehicular traffic is very high. With cropping up of unplanned colonies adjacent to these roads, they receive the maximum input of traffic exhaust pollutants converting them into localized high pollution zones. Several recent studies suggest an association between automobile exhaust and increased respiratory symptoms\(^6-9\). Since motor vehicle emissions are a major source of urban air pollution\(^10-12\), it has been observed that urban residents living near a roadway experience higher exposure to motor vehicle emissions compared to those living farther away, thereby experiencing a higher health risk. A number of studies have been conducted to describe the distance decay relationship of pollutants near busy roadways. Species such as particulate matter with an aerodynamic diameter less than 2.5 µm (PM\(_{2.5}\)), particulate matter with aerodynamic diameter less than 10 µm (PM\(_{10}\)), NO\(_x\), SO\(_2\) and black smoke (BS) have been studied with distance gradients around busy roadways. Decrease in the background levels of BS, PM\(_{2.5}\), NO\(_2\) and benzene is found between 100 and 150 m around a major expressway in a European setting\(^13\). A 50% decrease in PM\(_{2.5}\) was found within 100-150 m from the road\(^14\). In another study over the total measured distance (0-228 m), the maximum decreases of PM\(_{10}\), PM\(_{2.5}\) and PM\(_{1}\) have been only 7, 9 and 10%, respectively at 2 m distance from the road\(^15\). The variation of ambient nitrogen dioxide (NO\(_2\)) concentration with increasing distance from a major highway in Montreal (Canada) have been studied and
a strong negative correlation has been found between NO$_2$ levels and distance from the highway$^{16}$. In a follow up study, concentrations of NO$_2$, in locations beyond 200 m from the nearest highway, increased with higher traffic counts on the nearest highway and with decreasing distance from the highway$^{17}$. A study, conducted in 2007, concluded that mean SO$_2$ concentrations gradually declined with the distance away from the highway and the steepest SO$_2$ concentration gradients occurred within 150 m from the highway$^{18}$. The distribution of PM$_{2.5}$, acidic and basic gases was investigated near a highway recently. The results indicated that concentrations were higher at near highway site than the far highway site$^{19}$. To investigate health effects and risk assessments of traffic related air pollution, it is imperative to assess the concentration and dispersion modes of the pollutants near the highway. The present paper examines the validity of distance from the highway as a measure of exposure to air pollution from traffic by conducting ambient measurements of total suspended particulate matter (TSPM), PM$_{10}$, sulphur dioxide (SO$_2$), nitrogen dioxide (NO$_2$), ozone (O$_3$), carbon dioxide (CO$_2$) and carbon monoxide (CO) at different distances from the highway.

2 Experimental methods

2.1 Study area

Agra, the city of the Taj, is located in north-central region ($27^\circ10'N$, $78^\circ02'E$) of India. Three national highways, NH-2, NH-3 and NH-11, cross the city. NH-2 is one of the busiest highways, which connect Delhi to Kolkata via Agra. On an average, on regular days six to seven thousand vehicles move on this highway$^{20}$. They are summed up as 3500 LMVs (cars/ vans/ jeeps), 500 LCVs (Matador/ Tata 407/ DCM Toyota/ Tractor-Trolley), 2500 HCVs (Buses/ Trucks/ Trawlers/ Tankers). The two locations, chosen for the present study, were Khandari (Site A) and New Kaushalpur (Site B), lying perpendicular to the highway as shown in Fig 1. Khandari is a very busy crossing on NH-2 with residential colonies lying sideways while New Kaushalpur is a densely populated residential area adjacent to NH-2 with a high level of vehicular pollution, caused by the highway and localized traffic congestions. At each of the two locations, three monitoring sites were set up at a distance of 0, 250 and 500 m from NH-2, i.e. A1 (0 m), A2 (250 m), A3 (500 m) and B1 (0 m), B2 (250 m), B3 (500 m).

2.2 Sampling and analysis

The present study was conducted during summer (April-June) 2007. The climate at the experimental sites during the summer season is associated with high temperature and hot, dry and strong winds (2.0-7.1 m s$^{-1}$). Daytime temperature ranges between 25.8 and 42.6$^\circ$C. May is the hottest month. Relative humidity in the summer ranges between 29.8 and 72.7%. The prominent wind directions during the
summer period are from north and west, i.e. north-north-west and west-north-west. Table 1 shows the statistics of meteorological conditions measured during the sampling period. The monitoring of pollutants was carried out for 24 h. Sampling rate was 4 h for SO$_2$ and NO$_2$; 2 h for O$_3$; 1 h for CO and CO$_2$; and 24 h for SPM. The frequency of observations was twice a week.

The measurements of SPM were conducted by high volume sampler APM 460DX (Envirotech, New Delhi), with the average flow rate not <1.1 m$^3$ min$^{-1}$ using 20.3 × 25.4 cm$^2$ Whatman glass micro-fiber filters with particle filtering capacity ranged 0.1 - 100 μm. All filters were maintained in a condition of 50% RH and 25°C for over 48 h and were then weighed before and after sampling. Concentrations were calculated by taking the difference between the final and initial weights of filter paper and dividing by the volume of air sample. The measurements of gases were conducted by handy sampler APM 821 (Envirotech, New Delhi) using impingers filled with the absorbing solution of 0.1 N sodium tetra chloro mercurate (TCM) to form a stable non volatile dichloro-sulfito-mercurate complex. The typical standard concentrations ranging between 0.5 and 2.0 ppm were used to plot a calibration curve. The accuracy of standard curve was 2%. The standards were runned in triplicate. After every five samples the standard was run to check the peak response. If the deviation was more than 2% recalibration was done. While analyzing the sample, the addition of acid bleached pararosaniline methylsulfonic acid was examined spectro-photometrically at a wavelength of 560 nm to determine SO$_2$ concentration in the air. The analytical errors were nominal and varied within ±10%. To determine collection efficiency, the air was sampled in to three impingers in a series and the concentration of SO$_2$ was determined separately in each. Maximum concentration was found in the first impinger with a variation of 96-99% in the other impingers. Two parallel sets of measurements were carried out to determine the reproducibility with an identical absorbing solution. The differences of the parallel measurements under ambient conditions were less than 4%.

Concentration of NO$_2$ was determined by Saltzman’s method as modified by Jacob and Hoccheiserc. The NO$_2$ was collected by bubbling air through a 20 ml solution of sodium hydroxide and sodium arsenite contained in a glass impinger. The typical standard concentration ranged 0.5 - 2.0 ppm. The same procedure, as in case of SO$_2$, was followed to obtain the calibration curve. While analyzing the sample, the addition of acid bleached pararosaniline methylsulfonic acid was examined spectro-photometrically at a wavelength of 540 nm to determine NO$_2$ concentration in air. The analytical errors were nominal and varied within ±10%. To determine collection efficiency, the same technique as for SO$_2$ was used. Maximum concentration was found in the first impinger with a variation of 94-97% in the other two impingers. Two parallel sets of measurements were carried out to determine the reproducibility with an identical absorbing solution. The differences of the parallel measurements under ambient conditions were less than 5%.

Air concentration of O$_3$ was determined by neutral KI buffer method. The sample of O$_3$ was collected by bubbling air through absorbing solution of 1% potassium iodide in 0.1 m phosphate buffer. The typical standard concentration ranged 0.5 - 2.0 ppm.

<table>
<thead>
<tr>
<th>Meteorological parameter</th>
<th>Mean</th>
<th>S D</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Temperature (°C)</td>
<td>31.7</td>
<td>2.1</td>
<td>25.8-42.6</td>
</tr>
<tr>
<td>Relative Humidity (%)</td>
<td>53.0</td>
<td>18.1</td>
<td>29.8-72.7</td>
</tr>
<tr>
<td>Wind Speed (m s$^{-1}$)</td>
<td>4.0</td>
<td>2.2</td>
<td>2.0-7.1</td>
</tr>
</tbody>
</table>

*Wind direction during the sampling period remained the same as west-north-west and north-north-west
The same procedure, as in case of SO\textsubscript{2}, was followed to obtain the calibration curve. The liberated iodine, which forms the triiodide ion, was measured directly at the wavelength of 352 nm using UV-visible spectrophotometer (Helios-α, Thermospectronic, UK). The analytical errors were nominal and varied within ±10%. Impingers were shielded from direct sunlight by covering them with a black sheet to avoid photodecomposition. Low temperature was maintained by putting the ice in the box, in which impingers were kept. To determine collection efficiency, the same technique as for SO\textsubscript{2} was used. Maximum concentration was found in the first impinger with a variation of 91-94% in the other two impingers. Two parallel sets of measurements were carried out to determine the reproducibility with an identical absorbing solution. The differences of the parallel measurements under ambient conditions were less than 6%.

The concentration of CO was measured by YES-205 multi-gas monitor (Young Environment System Inc 140-8771 Douglas St. Richmond, B.C. V6X1V2, Canada) using Non Dispersive Infra-Red (NDIR) sensor. The monitor measures CO in the interval of 0-50 ppm with a resolution of 0.3 ppm. Zero and span were checked at regular intervals using zero air and standard of CO. The concentration of CO\textsubscript{2} was measured by a portable YES-206 Falcon IAQ monitor (Young Environment System Inc 140-8771 Douglas St. Richmond, B.C. V6X1V2, Canada), using Non Dispersive Infra-Red (NDIR) sensor. Zero and span were checked at regular intervals using zero air and standard of CO\textsubscript{2}. At the time of measuring CO and CO\textsubscript{2}, temperature and relative humidity were also measured.

### 3 Results and discussion

This study reports pollution gradients and associations between pollutants monitored near a national highway. Measurements were conducted simultaneously and the same sampling equipment, sampling procedures and the laboratory techniques were used at both the sites. The results of ambient measurements at the extensive monitoring sites i.e. Khandari (Site A) and New Kaushalpur (Site B), perpendicular to the highway are shown in Table 2. Average concentration along with standard deviation is given for TSPM, PM\textsubscript{10}, SO\textsubscript{2}, NO\textsubscript{2}, O\textsubscript{3} and CO\textsubscript{2} separately at site A and site B. The T-test has been applied for comparing mean-values of pollutants obtained at different distances. The p-value for SO\textsubscript{2}, NO\textsubscript{2}, CO, TSPM at A1-A2 was ≤ 0.01 which signifies 99% difference in their mean values. The p-value for SO\textsubscript{2} and CO at B1-B2 was ≤ 0.01 which signifies 99% difference in their mean values whereas for NO\textsubscript{3} and TSPM at B1-B2 p-value ≤ 0.05 which shows 95% significant difference in their mean values. The p-value for SO\textsubscript{2}, NO\textsubscript{2}, CO, TSPM at B2-B3 was ≤ 0.05 which signifies 95% difference in their mean values. The p-value for O\textsubscript{3}, PM\textsubscript{10} at A1-A2 and A2-A3, B1-B2 and B2-B3 was ≤ 0.05 which shows 95% significant difference in their mean values. However, in case of CO\textsubscript{2}, no significant difference is obtained between mean values at different distances. The above results confirmed that the average concentrations of all pollutants (except CO\textsubscript{2}) are decreasing with a significant difference in their values. Thus, ambient concentrations are found higher close to highway and decline with the distance from the highway. Higher pollution at highway is attributed

<table>
<thead>
<tr>
<th>SITE A</th>
<th>Mean (standard deviation) concentration per distance from the roadside</th>
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<tbody>
<tr>
<td></td>
<td>0 m (A1)</td>
</tr>
<tr>
<td>TSPM (µgm\textsuperscript{-3})</td>
<td>1068.93 (108.58)</td>
</tr>
<tr>
<td>PM\textsubscript{10} (µgm\textsuperscript{-3})</td>
<td>349.20 (104.62)</td>
</tr>
<tr>
<td>SO\textsubscript{2} (µgm\textsuperscript{-3})</td>
<td>38.65 (12.31)</td>
</tr>
<tr>
<td>NO\textsubscript{2} (µgm\textsuperscript{-3})</td>
<td>22.59 (4.12)</td>
</tr>
<tr>
<td>O\textsubscript{3} (µgm\textsuperscript{-3})</td>
<td>56.34 (16.60)</td>
</tr>
<tr>
<td>CO (µgm\textsuperscript{-3})</td>
<td>1183.37 (346.36)</td>
</tr>
<tr>
<td>CO\textsubscript{2} (µgm\textsuperscript{-3})</td>
<td>945869.80 (13102.52)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SITE B</th>
<th>Mean (standard deviation) concentration per distance from the roadside</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 m (B1)</td>
</tr>
<tr>
<td>TSPM (µgm\textsuperscript{-3})</td>
<td>570.77 (171.03)</td>
</tr>
<tr>
<td>PM\textsubscript{10} (µgm\textsuperscript{-3})</td>
<td>161.62 (56.78)</td>
</tr>
<tr>
<td>SO\textsubscript{2} (µgm\textsuperscript{-3})</td>
<td>30.42 (5.25)</td>
</tr>
<tr>
<td>NO\textsubscript{2} (µgm\textsuperscript{-3})</td>
<td>20.58 (2.48)</td>
</tr>
<tr>
<td>O\textsubscript{3} (µgm\textsuperscript{-3})</td>
<td>40.93 (12.95)</td>
</tr>
<tr>
<td>CO (µgm\textsuperscript{-3})</td>
<td>877.98 (132.23)</td>
</tr>
<tr>
<td>CO\textsubscript{2} (µgm\textsuperscript{-3})</td>
<td>925192.10 (10232.96)</td>
</tr>
</tbody>
</table>
to diesel/petrol vehicular emissions, as the major source of pollution. The gradients with distance were curvilinear as shown in Fig 2. The monthly average concentration of TSPM, PM$_{10}$, NO$_2$, SO$_2$, CO and O$_3$ shows a clear decline with distance from the NH-2 at both the sites. For PM$_{10}$ and TSPM a decreasing trend is obtained as we move away from the highway because particulate matter pollution is affected directly by tailpipe exhaust from motor vehicles, brake/tire wear and resuspended road dust. The gradients of SO$_2$ also show a decreasing trend since SO$_2$ is usually emitted during the combustion of low quality fossil fuels and road traffic is one of the chief sources of fossil fuel pollution. In the case of CO, NO$_2$ and O$_3$, a similar pattern was observed with levels getting smaller as the distance to the highway increases. As a high load of traffic on the highway accounts for the formation of high amount of CO, NO and NO$_2$, it acts as a precursor of O$_3$ formation and thus causes high level of O$_3$ near the highway. As the distance increases from the highway, we move towards the residential area, with a less load of traffic.

Fig. 2(a) — Horizontal gradients of pollutants measured at different distances from the national highway at the two roadside locations
because of the presence of trees and green parks, all these conditions cause low levels of CO, NO and NO\textsubscript{2}, which in turn account for low O\textsubscript{3} concentration.

The steepest concentration gradients occurred within 250 m distance from the highway. To further confirm the above statement, the decrease in concentration has been calculated in terms of percentage from 0-250 m and 250-500 m distance from the highway for both the sites. The percent decrease values for TSPM, PM\textsubscript{10}, SO\textsubscript{2}, NO\textsubscript{2}, O\textsubscript{3} and CO observed within 0-250 m distance are: 54.0, 50.6, 23.6, 44.2, 20.6 and 41.7\%, respectively at site A and 43.6, 34.4, 36.2, 32.6, 18.7 and 47.3\%, respectively at site B whereas in 250-500 m distance range, the values are 24.4, 32.1, 20.3, 30.7, 8.0 and 38.9\%, respectively at site A and 23.5, 13.0, 17.6, 23.4, 6.8 and 33.2\%, respectively at site B. However, no significant decrease in concentrations of CO\textsubscript{2} was obtained with increasing distance. Thus, it can be concluded that the maximum percent decrease in concentration for all pollutants (except CO\textsubscript{2}) over the total measured distance range 0-500 m were found within 250 m distance from the highway (Fig. 3). It suggests that the major impact of traffic flow on the pollutants concentration lies within first 250 m distance from the highway. After analyzing the data, the average concentration levels of TSPM, PM\textsubscript{10}, SO\textsubscript{2}, NO\textsubscript{2}, O\textsubscript{3} and CO (except CO\textsubscript{2}) were found higher at site A than that at site B probably because of the local traffic present at site A. Since site A (Khandari) is a very busy crossing on NH-2 and sampling points are located along a local busy road passing through the crossing. Whereas site B (Kaushalpur) is a densely populated residential area adjacent to NH-2 and sampling points are located along local colony road with less traffic. Thus, the effect of localized traffic congestion is more visible at site A as compared to site B. The average concentrations were compared with prescribed standards given by CPCB\textsuperscript{22}. The average concentration of PM\textsubscript{10} was found 1.9, 2.8, 5.8

![Horizontal gradients of pollutants measured at different distances from the national highway at the two roadside locations](image-url)
times higher at site A3, A2, A1 and 1.5, 1.7, 2.6 times higher at site B3, B2, B1, respectively. The levels of NO\textsubscript{2}, CO, O\textsubscript{3} and SO\textsubscript{2} were within permissible limit. These high levels of pollutants found near highway may probably be accounted for respiratory problems found frequently in the residents living in near vicinity.

The degree of association between pollutants was investigated with the bivariate Pearson correlation (Table 3). Most of the variables were significantly correlated at 0.01 and 0.05 levels. There are inter-correlations between the pollutants with many of them being highly significant. NO\textsubscript{2} has strong to moderate association with increasing distance from the highway, with PM\textsubscript{10} (R ranges 0.99 ∼ 0.93), TSPM (R ranges 0.99 ∼ 0.35), SO\textsubscript{2} (R ranges 0.97 ∼ 0.52), CO (R ranges 0.96 ∼ 0.58) and O\textsubscript{3} (R ranges 0.99 ∼ 0.55). PM\textsubscript{10} shows significant correlations with TSPM (R ranges 0.96 ∼ 0.57), O\textsubscript{3} (R ranges 1.0 ∼ 0.37), CO (R ranges 0.99 ∼ 0.53) and SO\textsubscript{2} (R ranges 0.35 ∼ 0.97). TSPM also follows the same pattern with SO\textsubscript{2} (R ranges 0.02 ∼ 0.91). O\textsubscript{3} shows a very high positive correlation at all of the sites with CO (R ranges 0.99 ∼ 0.74) and SO\textsubscript{2} (R ranges 1.0 ∼ 0.78). SO\textsubscript{2} also shows strong association with CO (R ranges 0.99 ∼ 0.38).

The significant correlations indicate that the emission sources are somewhat similar, i.e. vehicular exhaust generated by the traffic density affects pollutants in some or other way. For some of the pollutants (like NO\textsubscript{2}, CO and SPM), it acts as a direct source of emission, while for other pollutants (like particulates, O\textsubscript{3} and SO\textsubscript{2}) it affects their source of generation indirectly. In case of CO\textsubscript{2}, correlations with other pollutants were not significant; it shows that the factors affecting the other pollutants were not similar as those affecting CO\textsubscript{2}. The above results signify that the SPM, NO\textsubscript{2}, CO, O\textsubscript{3} and SO\textsubscript{2} are traffic-generated or traffic-related pollutants.

4 Conclusions

In the present study, the relationship between concentration of traffic related air pollutants and distance from the national highway was observed. The gradients observed for all the pollutants considered were almost similar. A negative association was found between distance and concentrations of PM\textsubscript{10}, SO\textsubscript{2}, NO\textsubscript{2}, O\textsubscript{3}, CO and CO\textsubscript{2}. The pollutants level dropped off very rapidly in the first 250 m and then continued to decline slowly up to 500 m. However, no significant decrease in concentrations of CO\textsubscript{2} was obtained with increasing distance. Over the total measured distance (0-500 m), the maximum decrease in concentrations in terms of percentage for TSPM, PM\textsubscript{10}, SO\textsubscript{2}, NO\textsubscript{2}, O\textsubscript{3}, CO and CO\textsubscript{2} were observed in 0-250 m distance range which is 54.0, 50.6, 23.6, 44.2, 20.6 and 41.7%, respectively at site A and 43.6, 34.4, 36.2, 32.6, 18.7 and 47.3%, respectively at site B, of the maximum concentration occurring at 0 m. To investigate the degree of association of pollutants with each other, a statistical (Pearson) correlation between ambient concentrations of these pollutants was also carried out. It has been found that all the pollutants were well correlated with each other. The highly significant and positive correlations signify that the sources are almost similar, i.e. automobile exhaust, for all of the pollutants considered in this study. The study reveals that the average mass concentrations of SO\textsubscript{2}, NO\textsubscript{2}, O\textsubscript{3} and CO were within permissible limits, whereas concentration of PM\textsubscript{10} were found higher than the available standards. This is very harmful to the people living in nearby colonies, cropping up adjacent to national highway in an unplanned and haphazard manner. This study will help the city planners to know about the status of pollutants concentration.
adjacent to national highways and horizontally away from the highway at various distances. So proper planning can be done before approving the plan of residential colonies. This study is being continued to observe the trends of all the pollutants and their levels so as to cause minimum exposure to the residents.

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