

Effect of reduced traffic density on characteristics of particulate matter over Delhi

Vikas Goel^{1,2}, Sumit Kumar Mishra^{1,2,*},
Ajit Ahlawat^{1,2}, Chhemendra Sharma¹,
N. Vijayan^{1,2}, S. R. Radhakrishnan¹,
A. P. Dimri³ and R. K. Kotnala^{1,2}

¹Environmental Sciences and Biomedical Metrology Division, CSIR-National Physical Laboratory, Dr K. S. Krishnan Marg, New Delhi 110 012, India

²Academy of Scientific and Innovative Research (AcSIR), Kamla Nehru Nagar, Ghaziabad 201 002, India

³School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110 067, India

Road rationing policy, implemented in Delhi from 1 to 15 January 2016, reduced the traffic density. This particular event serves an opportunity to study the effect of reduced traffic density over particulate matter (PM) characteristics. The mean PM_{2.5} and black carbon (BC) mass concentration before, during and after the event were observed as 163.51 µg/m³ and 14.01 µg/m³, 186.98 µg/m³ and 19.87 µg/m³, 197.45 µg/m³ and 17.79 µg/m³ respectively. During the first week (1–7 January 2016), high PM_{2.5} mass concentration was observed while in the second week (8–15 January 2016), the concentration was relatively low. The concentration of elements like P, Cu, As and Pb was observed to be minimum during the event.

Keywords: Black carbon, elemental composition, PM_{2.5}.

PARTICULATE matter (PM) with aerodynamic size less than 2.5 µm (PM_{2.5}) is known to cause adverse health effects. It can penetrate into our lungs and exacerbate several respiratory and cardiovascular diseases¹. Air pollution was globally reported to be the fourth largest risk factor for premature deaths. Some studies report that high concentration of PM_{2.5} results in increased mortality and morbidity². In India, air pollution is reported to cause approximately 1.59 million deaths per year³. Delhi is well known for its bad winter air quality and it has recently been listed among the most polluted cities in the world by World Health Organization (2014). In Delhi, tail-pipe emission and road dust, both related to the transport sector, are major contributors of total PM_{2.5} mass concentration. Several government pollution control agencies together with National Green Tribunal (NGT) are implementing various control measures to improve the air quality of Delhi. In this context, Delhi government implemented a road rationing policy from 1 to 15 January 2016. This policy was applicable for the given period

(from 8 a.m. to 8 p.m.) on daily basis (except Sunday). According to this policy, 4W private vehicles whose registration numbers end with an odd number were permitted on roads on odd numbered dates while even numbered vehicles were allowed on even number dates. There were some exemptions on the type of vehicles like all compressed natural gas (CNG) fuelled 4W vehicles, government vehicles and two-wheelers (2W). The present case study aims at delineating the effects of the reduced traffic density on the PM characteristics.

In the present study, we have collected inhalable particles (PM_{2.5}), data on black carbon (BC) and aerosol optical depth (AOD) in tandem with the meteorological parameters over Delhi during December 2015 and January 2016. To better understand the effects of reduced traffic density, the sampling period was divided into three categories; phase 1 (P1; 1–31 December 2015), phase 2 (P2; 1–15 January 2016) and phase 3 (P3; 16–31 January 2016). The policy was implemented in P2 only; P1 and P2 serve as a control for pre- and post-period.

Sampling was carried out at the rooftop of the main building in the National Physical Laboratory campus, New Delhi (28.61°N, 77.20°E and 216 m above mean sea level (amsl)). Delhi is India's capital and supports a population of nearly 167.5 lakh people with a density of 11,297 people per sq. km. It lies at one edge of the Indo Gangetic Plain (IGP). Delhi experiences cold winters during December and January which increases PM_{2.5} concentration by many folds due to low atmospheric boundary layer height (ABL).

The sample collection was done using PM_{2.5} sampler (Envirotech[®] APM550) at a flow rate of 16.7 lpm (litre per minute). The PM_{2.5} particles were collected over the pre-weighed 47 mm teflon filters for bulk composition analysis. The policy was implemented from 8 a.m. to 8 p.m. during which time the particle collection was carried out. A total of 35 samples were collected during the entire sampling period. The samples were stored in desiccators to remove the moisture after which they were weighed. The BC mass concentration was measured simultaneously with PM_{2.5} collection using an aethalometer (Aethlabs, AE51) which records light attenuation due to atmospheric particles at 880 nm at an interval of every 10 sec and converts it into respective BC concentration. The meteorological parameters (temperature, relative humidity) were measured using met tower at a height of 30 m.

The 10 m wind (*u* and *v*) data at the Palam station (28.56°N, 77.11°E), Delhi from 15 December to 31 January for the period 2004–2016 was taken from the European Centre for Medium Range Weather Forecasts (ECMWF) Interim Re-Analysis data⁴. For anomaly calculation, we took the average of daily data (e.g. the average of every 15 December from 2004 to 2016 and so on) from 15 December to 31 January for the period of 2004–2016 and then subtracted the mean value from daily values

*For correspondence. (e-mail: mishrask@nplindia.org)

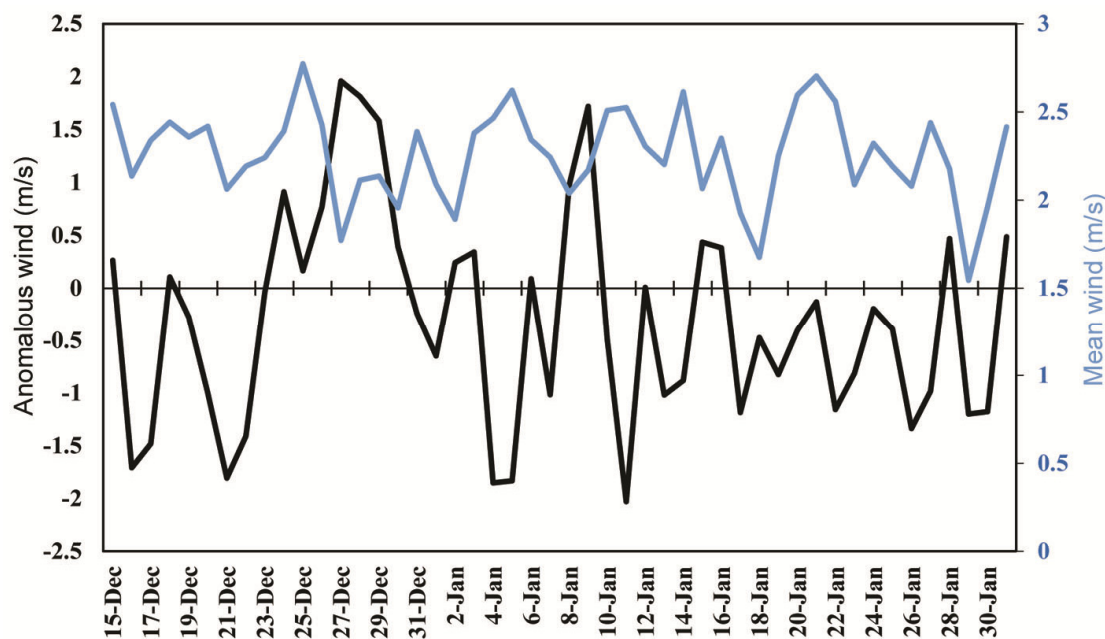


Figure 1. Time series plot of daily anomalous 10 m wind for the period 15 December 2015 to 31 January 2016 (black line) while blue line shows the daily mean of 10 m wind for the period 2004–2016 for 15 December to 3 January.

of only 15 December 2015 to 31 January of 2016, i.e. the anomaly line is only for 15 December 2015 to 31 January of 2016 (Figure 1).

Elemental mass concentration of the $PM_{2.5}$ particles collected over Teflon filters was measured by wavelength dispersive X-ray fluorescence spectrometer, WD-XRF (model: Rigaku ZSX primus). In XRF-spectrometer, the sample was exposed to X-rays that remove the electron from the inner orbital of atoms. This generates characteristic fluorescent X-rays which can be used to get a quantitative estimation of elements present in the sample.

The variation in meteorological parameters such as wind speed, temperature and relative humidity is shown in Figures 1 and 2. Maximum wind speed was observed during P1, relative humidity (RH) was observed to be minimum during P2 and maximum during P3, following the order $P3 > P1 > P2$. The corresponding temperature distribution showed maximum value during P2 and minimum value during P3, which follows the order $P2 > P1 > P3$. An inverse relationship was observed between temperature and RH. During the study period strong variability in meteorological parameters was observed which makes the problem complex while delineating the effect of reduced traffic density on PM characteristics.

During the study period, the BC mass concentration was observed to range from 6.7 to $40.33 \mu\text{g}/\text{m}^3$ (Figure 3). The average BC mass concentration during P1, P2 and P3 was measured to be $14.01 \mu\text{g}/\text{m}^3$, $19.87 \mu\text{g}/\text{m}^3$ and $17.79 \mu\text{g}/\text{m}^3$ respectively. The lowest ($6.7 \mu\text{g}/\text{m}^3$) and highest ($40.33 \mu\text{g}/\text{m}^3$) BC concentration was observed on 28 December 2015 (P1) and 7 January 2016 (P2) respectively.

In the first week of P2, very high BC concentration was observed that was attributed to the pre-suspended BC particles (BC has a residence time of ~ 7 days in atmosphere), very low wind speed (Figure 1) and an increase in the number of non-maintained vehicles on the road. In the second week of P2, the BC mass concentration decreased which may be attributed to the increase in wind speed (Figure 1) and to the wet deposition of BC particles because of dense fog event on 8 January 2016. During dense fog, the rate of conversion of sulphur dioxide to sulphate increases by many folds⁵ and the converted sulphate has a potential to form a hygroscopic layer around the hydrophobic BC particles. The processed BC captures moisture from the atmosphere and undergoes wet settling due to increased weight. The mean BC concentration was observed to be minimum during P1 that may be attributed to high wind speed and moderate temperature. In the present study, the mean BC concentration during winter season was $17.82 \pm 8.4 \mu\text{g}/\text{m}^3$, similar to earlier studies reported over Delhi in winters; $14.4 \mu\text{g}/\text{m}^3$ (ref. 6), $25.5 \mu\text{g}/\text{m}^3$ (ref. 7) and $15.93 \pm 2.06 \mu\text{g}/\text{m}^3$ (ref. 8).

According to a report by IIT Kanpur, vehicular emission is the second largest source of $PM_{2.5}$ in Delhi (<http://cpcb.nic.in/Delhi.pdf>; IITK, 2016). The observed variation in $PM_{2.5}$ mass concentration is in good agreement with that of AOD measurements taken using Microtop (Figure 4). In the entire study period, the $PM_{2.5}$ mass conc. and AOD was observed to range from 21.94 to $283 \mu\text{g}/\text{m}^3$ and 0.09 to 2.40 respectively. The average $PM_{2.5}$ concentration during P1, P2 and P3 period was $163.51 \mu\text{g}/\text{m}^3$, $186.98 \mu\text{g}/\text{m}^3$ and $197.45 \mu\text{g}/\text{m}^3$ respectively. During P2, $PM_{2.5}$ mass concentration was observed

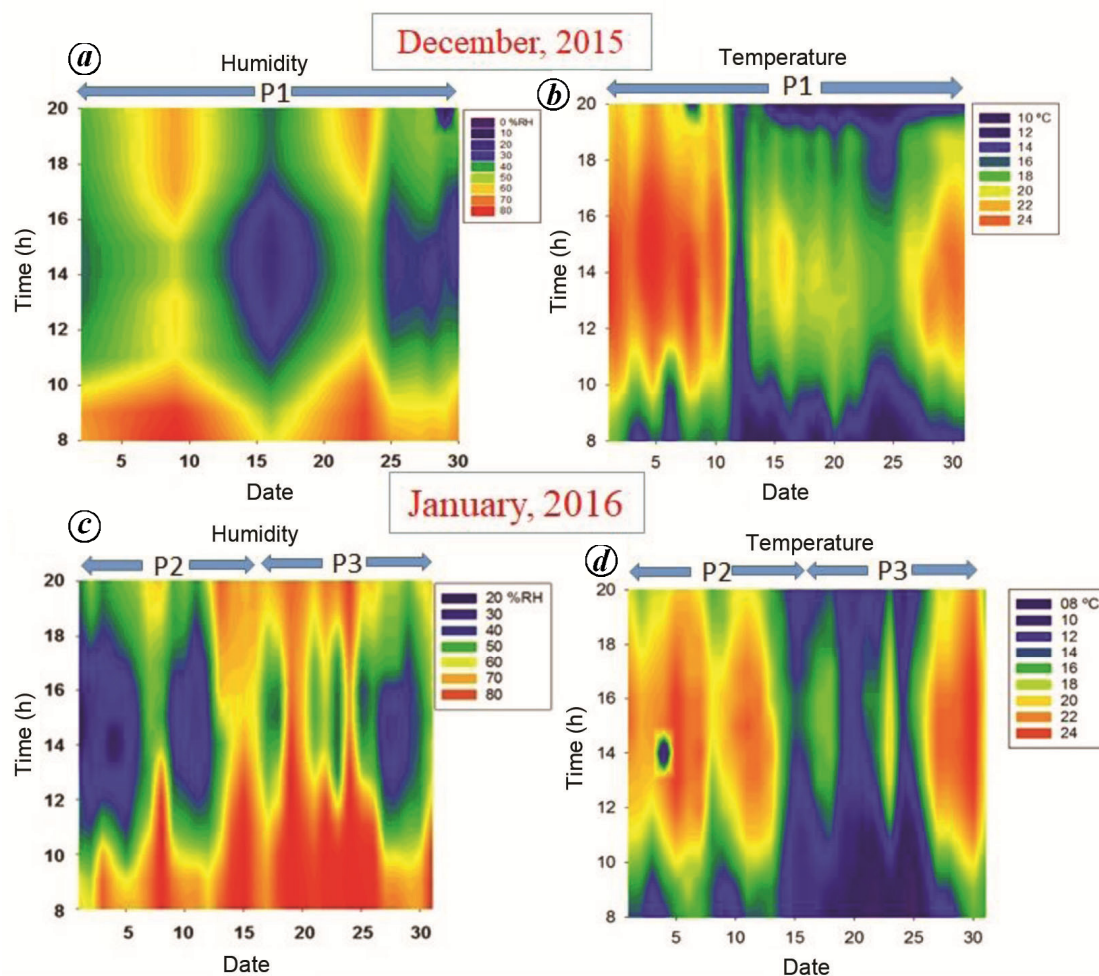


Figure 2. Temporal variation of temperature and relative humidity during P1 (1–31 December 2015), P2 (1–15 January 2016) and P3 (16–31 January 2016).

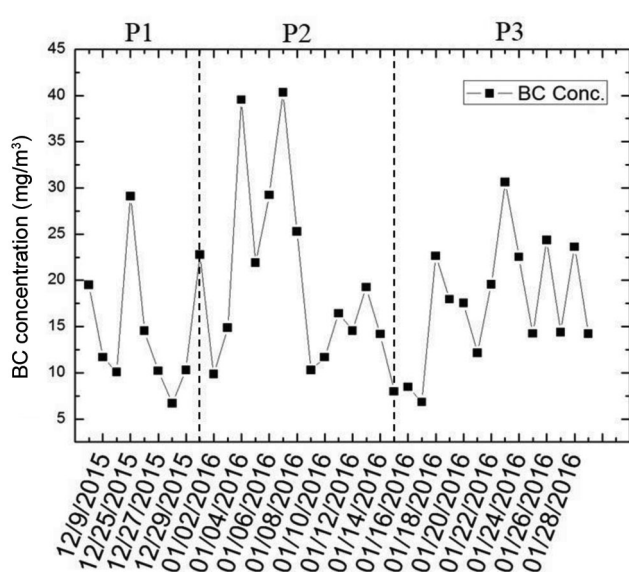


Figure 3. Temporal variation of BC concentration during P1, P2 and P3.

to vary from $69 \mu\text{g}/\text{m}^3$ to $274 \mu\text{g}/\text{m}^3$ with a mean mass concentration of $186.98 \mu\text{g}/\text{m}^3$. This is substantially higher than the standards set by Indian National Air Quality Standard (i.e. $60 \mu\text{g}/\text{m}^3$ (www.cpcb.nic.in)) and the US National Ambient Air Quality Standards (i.e. $35 \mu\text{g}/\text{m}^3$). $\text{PM}_{2.5}$ mass concentration was observed to be maximum during P3 which can be attributed to the low ambient temperature (gives rise to low convective activities) and low wind speed. During P1, the minimum $\text{PM}_{2.5}$ mass concentration was observed that may be attributed to relatively higher temperature and high wind speed. During P2, there was a strong variability in $\text{PM}_{2.5}$ mass concentration. The mean $\text{PM}_{2.5}$ concentration in the first week was very high ($224.53 \mu\text{g}/\text{m}^3$) followed by a sharp decrease in the second week ($171.66 \mu\text{g}/\text{m}^3$). During P2, the high concentration in the first week as compared to the second week was attributed to the low wind speed in the first week (Figure 1). In the second week, the significant increase in wind speed (Figure 1) and wash out effect due to dense fog on 8 January 2016 (wet scavenging)

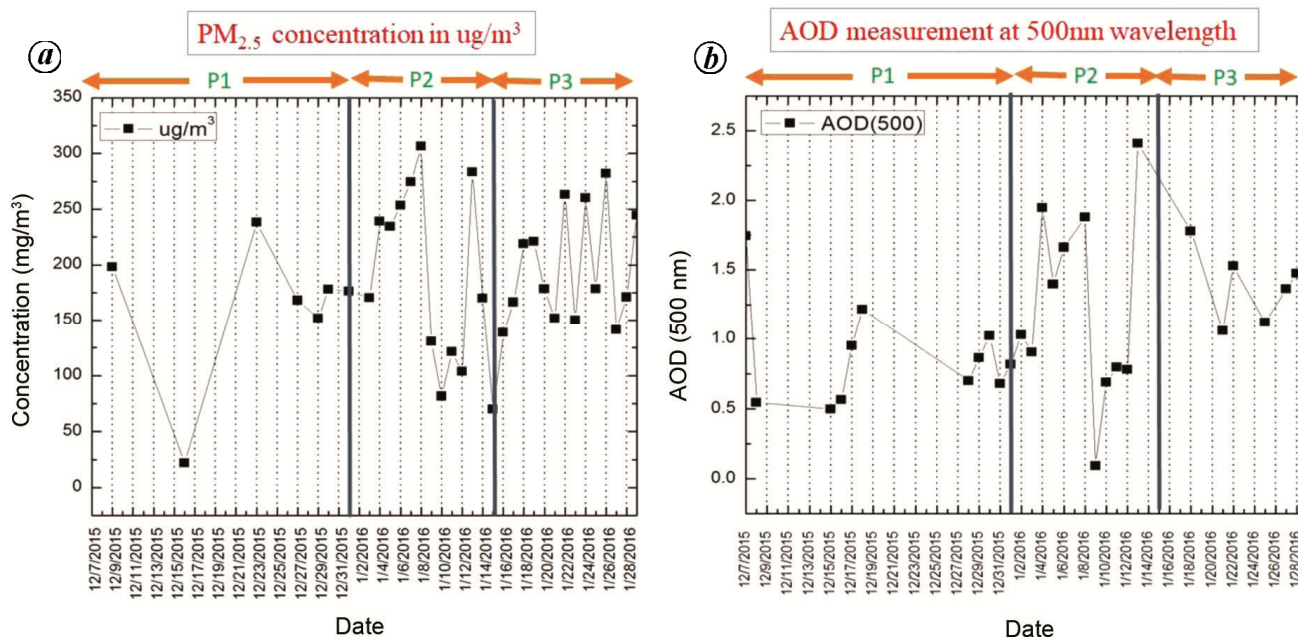


Figure 4. Variation in (a) PM_{2.5} mass concentration and (b) AOD data (at 500 nm wavelength) for the study period.

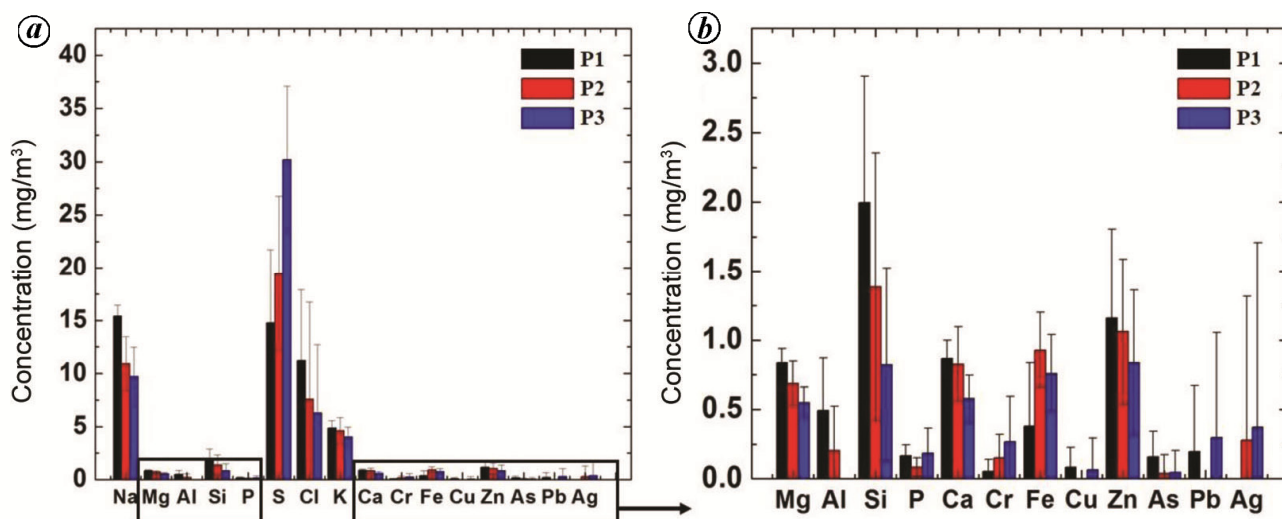


Figure 5. Elemental mass concentration of PM_{2.5} samples during the study period. (a) All elements, (b) zoom in chart of trace elements shown in black box in (a).

could cause the sharp decrease observed in PM_{2.5} mass concentration. In the first week of P2, an increasing pattern of PM_{2.5} mass concentration was observed. The increasing pattern may be due to the following reasons: (i) first three days of the week were holidays (weekend, 1–3 January); (ii) since Monday (full working days, 4–7 January), and there was probably rise in the use of non-maintained old vehicles (2W and 4W; due to road rationing policy enforcement). During the entire study period, the effect of reduced traffic density on PM concentration was superimposed by the high degree of variation in meteorological parameters.

The elemental mass concentrations of different elements in PM_{2.5} during P1, P2 and P3 are shown in Figure 5. Arsenic (As) and lead (Pb) are toxic and cause several diseases in human beings; Pb is a neurotoxin and well known for its adverse effects on pregnant women and children. Pb, Cu (copper), Zn (zinc) and Fe (iron) can be used as potential markers of brake wear and are well linked with the transport sector^{9,10}. Magnesium (Mg), calcium (Ca), silica (Si), sodium (Na), chlorine (Cl), potassium (K), chromium (Cr) and iron (Fe) serve as signatures of roadside dust or mineral dust re-suspended into the air due to traffic movement and wind^{11,12}. These

elements do not come directly from vehicular exhaust but are positively correlated with the vehicle density on road. In the study period, elements like As, Cu, Pb and P were observed to be most affected due to reduced traffic density.

Although the reduced traffic density does not have a pronounced effect on PM_{2.5} mass concentration, the effect is visible on elemental mass concentration of Cu, As and Pb; their concentration was found to be least during P2. The concentration of dust related elements (road dust) was also observed to be low during P2 as compared to P1 and is attributed to the decrease in the number of vehicles on the road due to policy enforcement. More vehicle density on road enhances the emission of road side dust. However, the concentration further decreased in P3 which may be due to the high humidity. In high humid environment, the road side dust captures the moisture and becomes less probable to be emitted in the atmosphere limiting road-side dust emission. The concentration of sulphur is found to be high during P2 as compared to P1 due to dense fog events which facilitates its conversion. Sulphur (S) is present in the atmosphere in the form of sulphate that is formed by homogeneous and heterogeneous reaction of sulphur dioxide¹³. In homogeneous conversion, the SO₂ molecules get oxidized to SO₄²⁻ by reacting with other gaseous species like NO₂, O₂, O₃, OH⁻, NO₃, hydrocarbons and some other heavy metals. SO₂ molecules can also react with each other and form SO₃ that can be oxidized to SO₄²⁻ by reacting with water droplets or other gases. In heterogeneous conversion, the oxidation of SO₂ to SO₄²⁻ takes place on the surface of solid species like carbon, metal oxides or other species. The conversion rate of SO₂ to SO₄²⁻ increases during high humidity or dense fog events¹⁴. In P3, the sulphur concentration reaches its maximum due to high traffic density and high relative humidity. High concentration of sulphate in air can have long-term health impact and can cause several diseases^{2,15,16}.

The fate of air pollution depends on the cumulative effect of various parameters like meteorological conditions (temperature, humidity, temperature inversion conditions and wind speed) and emissions from various sources. The daily variation in meteorological parameters makes it very difficult to delineate the effect of traffic density on PM concentration. Although there may be a reduction in the level of few pollutants, the decrease in the number of vehicles was not sufficient to make a visible change in PM characteristics over Delhi. Concentration of elements like Cu, As, Pb and P declined during the reduced traffic period confirming the effect of traffic on trace metals concentration.

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