Significance of PM$_{2.5}$ Air Quality at the Indian Capital

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ABSTRACT

In New Delhi, the capital city of India, concentrations of regulated air pollutants often exceed the Indian national ambient air quality standards (INAAQS). As the sources of these pollutants differ, it is of utmost priority to understand the most dangerous air pollutant to formulate better control strategies in the city. In this study, regulated air pollutant concentrations in New Delhi during 2011 to 2014 were collected. Compared to other pollutants, PM$_{2.5}$ concentrations exceeded the INAAQS quite often. While PM$_{2.5}$ exceeded INAAQS during 85% of the days, NO$_2$, O$_3$, CO and SO$_2$ exceeded only on 37, 14, 11 and 0% of the days, respectively. Using air quality index approach, the most dominant pollutant was identified as PM$_{2.5}$, for 75 to 90% of the days. However, a seasonal variation in the percentage dominance of PM$_{2.5}$ was observed. For example, PM$_{2.5}$ was dominant during 95% of the winter and 68% of monsoon days. In addition to absolute concentrations, pollutants can also be ranked by studying their associated short term mortality impacts. However, such studies are rare in India. For the first time, the short term impact of PM$_{2.5}$ concentrations on non-disease specific mortality in New Delhi was assessed using Poisson regression models. Results indicated that the excessive risk associated with PM$_{2.5}$ estimated was 0.57, which was higher than the other regulated pollutants. This indicates a projected 6.2 and 6.5% decrease in mortality by meeting the PM$_{2.5}$ Indian standards and WHO set limits, respectively.

Keywords: Air quality index; New Delhi; PM$_{2.5}$; Health impact assessment.

INTRODUCTION

A world health organization (WHO) report observes that air pollution resulted in around seven million deaths globally in 2012, of which South East Asian region, dominated by India, accounted for 2.3 million (WHO, 2014a). Outdoor particulate matter (PM) was the seventh highest killer in India during 1990–2010 (IHME, 2013). According to a recently released report (WHO, 2014a) by World Health Organization (WHO), among 1600 cities surveyed, thirteen of the Indian cities were among the top twenty worst polluted cities, with New Delhi leading the list. PM$_{2.5}$ concentrations in New Delhi are atleast10 times higher than Washington DC, and 3 times higher than Beijing (WHO, 2014a). In order to construe the status of air quality in India, National Ambient Air Quality Standards (INAAQS) were adopted in 1982 by the Central Pollution Control Board, with further revisions in 1994 and 2009. Predominant sources for these regulated pollutants differ. For example in New Delhi, residential, transport and industrial sectors are major sources for PM$_{2.5}$ (Sahu et al., 2011); transport sector is the major source of CO and NO$_x$ (Aneja et al., 2001); and industries are major source for SO$_2$ (Sadavarte and Venkataraman, 2014). So this calls for knowledge about the most dangerous pollutant in the city to formulate stricter laws and better control strategies.

As the absolute concentrations of these pollutants differ, it is necessary to bring these pollutants onto a similar scale for direct comparison. To alleviate this, Ott (1978) suggested a scheme to transform the weighted values of air pollutant concentrations into a single or set of numbers, referred to as Air Quality Index (AQI), wherein bigger the AQI greater the pollution, higher is the health risk, and vice versa. The quality of air is reported as good, satisfactory, moderate, poor, very poor or severe depending on the overall AQI, calculated using individual AQI of pollutants considered. Several developed nations in the world, including the US, UK, Australia, and Canada, have their own AQI. These vary by the range of the index, and the methodology used to estimate species specific and overall AQI. For example, UK (COMEAP, 2011) and Canada (Chen and Copes, 2013) classify AQI into four categories, with AQI ranging from 0 to 10. However, the US uses six categories, ranging from 0 to 500. Moreover, while Canada uses a non-linear aggregate of AQI of different species based on their exposure-response relationships, the US and UK use maximum AQI of different species, to estimate the overall AQI. Few studies in India, tried to analyze air quality using AQI in cities.
respectively and obtained the risk co-efficient of PM 10, (2011) did a time series study on Chennai and New Delhi cities. Balakrishnan estimate cause specific premature death from ambient PM2.5 of CO, SO2, PM10, O3 and NO2, to compare AQI estimated the year. Bishoi indicated moderate to heavy air pollution, for most part of the year. Bishoi et al. (2009) used yearlong concentrations of CO, SO2, PM10, O3, and NO2, to compare AQI estimated using the US methodology and factor analysis. Results show that while both methodologies follow similar trends, the US methodology estimated higher AQI than factor analysis.

However, in order to quantify the health risk posed by a pollutant, it is essential to study the association between pollutant exposure and health outcome. These studies also aid regulatory agencies in fixing the pollution reduction targets to a level that would minimize the health risk of the exposed group. Health risk based studies are quite common in western countries. Cohen et al. (2005) observed that the relationship between relative risk and cardiopulmonary diseases, lung cancer, and acute respiratory infections in children was linear between PM2.5 concentrations of 7.5 µg m–3 to 50 µg m–3, and flattened thereafter. Pope et al. (2009) observed that a nonlinear power function expressed the relationship between relative risk of ischemic heart disease, cardiovascular disease and cardiopulmonary disease mortality from cigarette smoking. Results also indicated that initially cardiovascular disease mortality increased steeply with increase in concentration of fine particulate matter and flattened out at higher exposure concentrations.

In India, mainly due to lack of mortality data, there are very few studies relating health risk and pollutant concentrations. Dholakia et al. (2014) studied the short term association between PM10 concentration and mortality for five Indian cities. Balakrishnan et al. (2011) and Rajaratnam et al. (2011) did a time series study on Chennai and New Delhi respectively and obtained the risk co-efficient of PM10, NO2 and SO2. Similarly, Gutikunda and Goel (2013) studied the health impacts of PM10 and PM2.5 in New Delhi using exposure response coefficients from Atkinson et al. (2012). Chowdhury and Dey (2016) used satellite data for calculating nationwide PM2.5 exposure and a risk model to estimate cause specific premature death from ambient PM2.5 exposure. However, no short-term exposure response study of PM2.5, which is the best indicator to the health risk levels from air pollution (WHO, 2014b), was carried out to our knowledge in India.

The objective of this study is to identify the most dangerous pollutant in New Delhi by AQI and health risk based approaches using ambient concentrations of regulated pollutants and health based mortality in New Delhi during 2011 to 2014.

MATERIAL AND METHODS

Indian AQI

CPCB set guidelines for Indian national ambient air quality standards of 12 pollutants (CPCB, 2009). Out of which 8 pollutants CO, NO2, SO2, PM2.5, PM10, O3, Pb and NH3 have short term standards. To inform people about the quality of air quickly so that people can take appropriate measures to protect themselves, IND-AQI was released in 2014. The details of IND-AQI are available elsewhere (CPCB, 2014), and only briefly summarized here. IND-AQI considers concentrations of PM10, PM2.5, NO2, O3, CO, SO2, NH3 and Pb. In a day, while maximum 8 hour running average concentrations of O3 and CO are used, 24 hour averaged concentrations of other six pollutants are used in calculation. The concentration of each pollutant is converted to a number on a scale of 0–500. The sub AQI (AQIi) for each pollutant (i) is calculated using Eq. (1)

\[
\text{AQI}_i = \frac{I_{\text{HI}} - I_{\text{LO}}}{BR_{\text{HI}} - BR_{\text{LO}}} \times (C_i - BR_{\text{LO}}) + I_{\text{LO}}
\]  

where, \(C_i\) is the concentration of pollutant ‘i’; \(BR_{\text{HI}}\) and \(BR_{\text{LO}}\) are breakpoint concentrations greater and smaller to \(C_i\) and \(I_{\text{HI}}\) and \(I_{\text{LO}}\) are corresponding AQI ranges.

The overall AQI, IND-AQI, can be estimated only if the concentrations of minimum three pollutants are available, with at least one of them being either PM2.5 or PM10. The IND-AQI is then taken as the maximum AQI of the constituent pollutants, denoted as dominating pollutant. The IND-AQI is divided into five categories: good, satisfactory, moderate, poor, very poor and severe depending on whether the AQI falls between 0–50, 51–100, 101–200, 201–300, 301–400 or 401–500, respectively. IND-AQI calculation can be better understood by the following example: Consider a day in New Delhi with the 24-hr concentrations of PM2.5, SO2, NO2, and maximum 8-hr concentration of CO, O3 as 135 µg m–3, 13 µg m–3, 12 µg m–3, 3 mg m–3, and 84 µg m–3, respectively. Using the breakpoint concentrations in Table 1 and Eq. (1), the AQIi of PM2.5, SO2, NO2, CO and O3 are calculated as 311.75, 16.25, 15, 112.27 and 84, respectively. The IND-AQI of that day would be 311.75, and PM2.5 would be termed as the dominant pollutant.

Health-Risk Associated with a Pollutant

This study uses excessive risk of the pollutants (ERi) given by Cairncross et al. (2007), as shown in Eq. (2):

\[
ER_i = \exp(\beta(C_i - C_{\text{min},i})) - 1, \quad C_i > C_{\text{min},i}
\]  

where, \(\beta\) is the exposure-response relationship coefficient, represents the increase in mortality per unit increase in concentrations.

The time series Poisson regression models are widely used to analyze the relation between pollutant concentrations and mortality (Dholakia et al., 2014). The Poisson model used in this study, represented using Eq. (3), is described elsewhere (Bhaskaran et al., 2013; Imai et al., 2015).
the already deteriorating air pollution in New Delhi. Four
2011–2014. Such extreme temperatures can severely affect
2016). It received an average rainfall of 889.2 mm from
temperature of as low as 7°C in winter to as high as 48°C in summer (WU,
11,297 per sq. km. It faces extreme temperatures of as low
growth rate of 1.92%. The overall population density is
also one of the most densely populated cities in the world.

### Study Area and Data Sources

New Delhi, in addition to being the capital of India, is also one of the most densely populated cities in the world. It has a population of 16.7 million with an annual average growth rate of 1.92%. The overall population density is 11,297 per sq. km. It faces extreme temperatures of as low as 7°C in winter to as high as 48°C in summer (WU, 2016). It received an average rainfall of 889.2 mm from 2011–2014. Such extreme temperatures can severely affect the already deteriorating air pollution in New Delhi. Four years data ranging from January 1st, 2011 to December 31st of 2014 was used for the analysis. The data was collected at a busiest traffic intersection, Bahadur Shah Zafar Marg (ITO) located at commercial downtown of the city, as shown in Fig. 1. Hourly concentrations of CO, O₃, NO₂, SO₂, and PM2.5 were collected by Central Pollution Control Board (CPCB). Pollutant concentrations vary across a city. However, this is the longest period for which hourly data of these species is available in any location in New Delhi. In such situations studies resort to analysis of data collected at a single location. For example, Kim et al. (2015) studied the association of selected components of PM2.5 on mortality, using PM2.5 data obtained from a centrally located residential site in Denver. Similarly, Garrett and Casimir (2011) studied the short term effect of PM2.5 and O₃ in Lisbon, using data obtained from a monitoring station in Olivais since this was the only station with data for both pollutants. Thus, in this study it is assumed that the concentrations observed in this location are representative of the entire city.

CO was measured using non-dispersive infrared spectroscopy, O₃ and NO₂ using Chemiluminescence, SO₂ using ultra violet fluorescence, and PM2.5 using tapered element oscillating microbalance. As hourly PM₁₀ concentrations were not available in this location, PM₂.₅ is assumed to be the sole representative of particulate matter in this study. Due to unavailability of data, the percentage of days on which the IND-AQI was not calculated, was 19, 42, 41 and 60 in 2011, 2012, 2013 and 2014, respectively. The mortality data was obtained from the office of births and deaths registration in New Delhi. Due to unavailability of cause specific mortality, non-accidental mortality has been used in this study.

### RESULTS AND DISCUSSION

#### Yearly Variation of Ambient Air Pollutant Concentrations

In INAAQS, CO and O₃ have both hourly and eight hour standards, and PM₂.₅, SO₂ and NO₂ have daily and yearly standards. For comparison with INAAQS, the measured hourly data of PM₂.₅, SO₂ and NO₂ were converted into daily averaged concentrations, and the hourly concentrations of O₃ and CO were used to estimate daily maximum 8 hour running average. Fig. 2 shows the change in concentrations of PM₂.₅, SO₂, O₃, NO₂ and CO from 2011 to 2014. The percentage of days for each pollutant exceeded INAAQS is also shown. Results indicate that in contrary to other pollutants, PM₂.₅ had maximum median concentrations in 2013. Panel (a) in Fig. 2 shows that median PM₂.₅ concentrations in all the four years exceeded the corresponding INAAQS of 100 µg m⁻³. PM₂.₅ concentrations exceeded INAAQS during 80, 82, 86 and 90% of days in 2011, 2012, 2013 and 2014, respectively.

SO₂ concentrations never exceeded INAAQS in the four years, as observed from panel (b) of the figure. Similar conclusion was derived by Goyal and Sidhartha (2003) from their air quality analysis during 1996 to 2001 at New Delhi. This indicates that SO₂ may not be a major air pollutant in New Delhi. However, the contribution of SO₂ in the formation of secondary sulfate particles might be significant, and should be explored further. Panel (c) shows that O₃ concentrations varied from 5 to 323 µg m⁻³ during the analysis period. O₃ concentrations exceeded the corresponding INAAQS of 100 µg m⁻³ for 16% in 2011, 26% in 2012, 0% in 2013, and 12% in 2014. Panel (d) shows that NO₂ concentrations exceeded the INAAQS of 80 µg m⁻³ limit 33.67% of the days in 2011, 62% of days in 2012, 15% of days in 2013, and 36% of days in 2014. CO concentrations reached a maximum of 10 mg m⁻³ during

### Table 1. Breakpoints of different pollutants in IND-AQI (CPCB, 2014).

<table>
<thead>
<tr>
<th>AQI Category (Range)</th>
<th>PM₂.₅</th>
<th>NO₂</th>
<th>O₃</th>
<th>CO</th>
<th>SO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>24-hr</td>
<td>50</td>
<td>80</td>
<td>100</td>
<td>1.0</td>
<td>40</td>
</tr>
<tr>
<td>8-hr</td>
<td>50</td>
<td>80</td>
<td>100</td>
<td>1.0</td>
<td>40</td>
</tr>
</tbody>
</table>

Note: While CO concentrations are expressed in mg m⁻³; the other pollutants are expressed in µg m⁻³.

log(µt) = γ + βCt + α(Kt + f(t))

where t denotes time; α, γ and β are the regression coefficients; µ is related to mortality; K denotes temperature; and f(t) is a smooth function of time. The spline function of time is used to remove seasonal and long term trends so that short term variation between concentration and mortality can be studied (Bhaskaran et al., 2013).

In Eq. (2), Cᵢ refers to the measured concentration and Cᵢᵣᵢ refers to the concentration of a pollutant below which no adverse health effects can be expected. According to WHO (2005), adverse health effects can be expected for any concentration of PM₂.₅, O₃, NO₂ and SO₂. Thus, in this study Cᵢᵣᵢ of all pollutants except CO, is considered as 0. Cᵢᵣᵢ for CO is considered as 2 mg m⁻³, as suggested by (CPCB, 2014), and shown in Table 1.
Fig. 1. An interactive map showing the study region (Delhi) and the location of the monitoring station (ITO) in India.

Fig. 2. Change in concentrations of CO, NO₂, O₃, SO₂ and PM₂.₅ from 2011 to 2014 at New Delhi. While the left Y-axis shows the concentrations, represented using box whisker plots, the right Y-axis, represented using red crosses indicates the percentage of data which exceed the INAAQS. The box whisker plots show minimum, maximum, median, upper and lower quartiles. Note: The range of y-axis of all panels is curtailed for better representation of the figure.
the period. Panel (e) shows that CO exceeded corresponding INAAQS value of 2 mg m\(^{-3}\); 14%, 11%, 9.4% and 9.2% of days in 2011, 2012, 2013 and 2014, respectively. This implies that PM\(_{2.5}\) is the major pollutant, followed by NO\(_2\) and CO in New Delhi. However, more studies in New Delhi where both PM\(_{10}\) and PM\(_{2.5}\) concentrations are available are necessary in future to support this conclusion.

**Yearly Variation of IND-AQI**

The yearly variation of frequency of days falling in the six IND-AQI categories, good, satisfactory, moderate, poor, very poor and severe, during 2011–2014 is shown in Fig. 3. Due to the lack of availability of data of other pollutants only concentrations of PM\(_{2.5}\), CO, NO\(_2\), SO\(_2\) and O\(_3\) were used to estimate the IND-AQI in this study. The corresponding frequency of dominating species in each of those years is shown in Table 2.

PM\(_{2.5}\) was the dominant species in 74 to 90% of the days in those four years. Maximum dominance of NO\(_2\) was observed during 2011 (16%), and O\(_3\) during 2011 (8%). While none of these years had days dominated by SO\(_2\), CO dominance was around 9% in most of the years, except 2012. Zero dominant days of SO\(_2\) is expected as it never violates INAAQS, as observed from Fig. 2.

Fig. 3 indicates that at least 60% of the days in all the years were poor. Moreover, 70% of days in 2013 were either very poor or severe. In comparison, 44, 53 and 52% of such days exist in 2011, 2012 and 2014, respectively. This could be due to higher PM\(_{2.5}\) concentrations in 2013 as observed from Fig. 2. Only 6% of the days in all the four years were either good or satisfactory.

**Weekday-Weekend Variation of IND-AQI**

Data analysts have reported weekday and weekend differences in air pollutant concentrations around the world (Altshuler et al., 1995; Karar et al., 2006; Tiwari et al., 2015). To explore this, weekdays and weekend variation of IND-AQI was analyzed, and shown in Fig. 4. PM\(_{2.5}\) was the dominant pollutant during 83% and 82% on weekdays and weekends, respectively. Results indicate that air quality on weekends was only slightly better than weekdays. For example, 50% of weekends, in comparison to 52% of weekdays were in the IND-AQI category of very poor and severe. Similar conclusions were arrived by Kumar and Goyal (2011), who studied AQI, following the US methodology, at the same location during 2000 to 2006. However, these observations are in contrary to the assumption that at the sampling site, located at a busy traffic junction, where vehicle density is more on weekdays than weekends, air quality should be better on weekends.

**Seasonal Variation of IND-AQI**

Previous studies have shown higher concentrations of poly aromatic hydrocarbons, sulfates and nitrates in PM\(_{2.5}\) in New Delhi (Pant et al., 2015), which have a strong correlation with temperature and RH (Wang et al., 2005). Additionally, studies in this region showed a strong correlation of reactive pollutants like O\(_3\), with temperature and RH (Gaur et al., 2014). To explore this, seasonal differences in IND-AQI and dominant species as a function of relative humidity (RH) and temperature were studied, and shown in Fig. 5. The seasons were categorized as winter (December–February), pre-monsoon (March–May), monsoon (June–August) and post-monsoon (September–November). Analysis indicates that concentrations of all the pollutants decreased during monsoon. This is due to wet scavenging of pollutants due to higher precipitation during that season.

Panels (a) to (d), indicate that winter had highest, around 72%, and monsoon had least, 32%, very poor and severe days. Panels (e) to (h) show a clear decreasing trend of PM\(_{2.5}\) dominance from winter to post-monsoon. While, PM\(_{2.5}\) was dominant in 95% of days in winter, it dominated IND-AQI during 68 and 70% of days of monsoon and post-monsoon seasons, respectively. Moreover, CO dominated during 18% of days in monsoon, and both CO and NO\(_2\) dominated post-monsoon by around 13–14% of days each.

![Fig. 3. Change in frequency of days (%) in various IND-AQI categories from 2011–2014.](image-url)
Table 2. Variation of domination of pollutants during 2011 to 2014.

<table>
<thead>
<tr>
<th>Year</th>
<th>SO₂</th>
<th>NO₂</th>
<th>PM₂.₅</th>
<th>CO</th>
<th>O₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>0</td>
<td>2</td>
<td>81</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>2012</td>
<td>0</td>
<td>17</td>
<td>75</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>2013</td>
<td>0</td>
<td>2</td>
<td>88</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>2014</td>
<td>0</td>
<td>0</td>
<td>90</td>
<td>9</td>
<td>1</td>
</tr>
</tbody>
</table>

Previous studies have indicated that in addition to wet deposition, variation in atmospheric mixing layer heights, air flow pattern can also be a main reason for seasonal differences of pollutant concentrations in this region (Sahu et al., 2009; Bisht et al., 2015). To examine this further, 24-hr back trajectories, originating from the sampling location, were generated using National Oceanic and Atmospheric Administration’s Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model. Fig. S1, in the supplementary material, shows the diurnal variation in atmospheric mixing layer heights in different seasons. Analysis indicated that mixing layer heights peak in the afternoon, around 2 to 3 PM, with the least daily maximum mixing layer heights during winter.

Results in Fig. S2, in the supplementary material, show a clear seasonal pattern in air mass back trajectories in New Delhi. During winter and pre-monsoon, where more very poor and severe days are observed, air parcels might have originated in Punjab and Haryana, home of many coal-based power plants and industries. In contrary, air parcels could have originated in Rajasthan and Uttar Pradesh during monsoon, and Rajasthan and Punjab in post-monsoon. Thus, the seasonal differences and the negligible weekday-weekend difference observed in this study could be due to long range transport of air pollutants. Similar conclusions were arrived from a recent study (Ghosh et al., 2015), which predicted significant influence of neighboring states in PM₂.₅ concentrations, during 2008 to 2010, in New Delhi.

Estimation of Health Risk Associated with Pollutants

To estimate the potential risk associated with the
concentrations of a pollutant, excessive risk associated with a pollutant was calculated using Eq. (2). Fig. 6 shows the monthly averaged PM$_{2.5}$ concentrations, temperature and non-accidental deaths at New Delhi during the analysis period. Estimated increase in non-accidental mortality, was 0.69% (95% CI: 0.17%, 1.21%), 0.88% (95% CI: 0.14%, 1.63%), and 3.77% (95% CI: −0.6%, 8.34%) per 10 µg m$^{-3}$ increase of PM$_{2.5}$, NO$_2$, and 1 mg m$^{-3}$ CO, respectively.

The ER values were obtained as 0.57 (95% CI: 0.45, 0.69), 0.36 (95% CI: 0.24, 0.46), and 0.052 (95% CI: 0.046, 0.058) for PM$_{2.5}$, NO$_2$, and CO, respectively. Non-significant risk factors were obtained for SO$_2$ and Ozone. This clearly indicates that PM$_{2.5}$ is associated with major health risk in New Delhi. Even though, Eq. (2) is commonly used (for example, see Hu et al. (2015)), it doesn’t consider the possible non-linearities in the exposure-response curve observed by some previous studies (Cohen et al., 2005; Pope et al., 2009; Burnett et al., 2014). Moreover, most of the health studies tend to depict the correlation between PM$_{2.5}$ concentrations and specific respiratory or heart diseases. However, in New Delhi disease specific mortality was not available during the analysis period. To study this further, the RR for average PM$_{2.5}$ concentration of 133 µg m$^{-3}$ at New Delhi was compared to that of Burnett et al. (2014). While, RR was 1.57 from the Eq. (2) used in this study, it was 1.4585, 1.658 and 2.662 for COPD, lung cancer and ALRI mortality, respectively from the integrated exposure function used in Burnett et al. (2014). Thus the overall risk of mortality obtained in this study lies within the range of values obtained using integrated risk function.

Table 3 shows the % increase in non-accidental mortality per 10 µg m$^{-3}$ increase in PM$_{2.5}$ concentration estimated by different studies around the world. In comparison with other major countries, no such studies were done in India. This indicates that exposure-response relation for PM$_{2.5}$ is similar in major cities in the world. This value lies in the range of global estimate by Atkinson et al. (2014), and closer to several studies in China (Dai et al., 2004; Chen et al., 2011) and the US (Ostro et al., 2006).

Furthermore, to better cogitate its associated health benefits, the possible number of non-accidental deaths averted by reducing PM$_{2.5}$ concentrations, to suggested levels by WHO and INAAQS was estimated following Shang et al. (2013). The expected number of premature deaths (PD)
Table 4. Projected reduction in non-accidental mortality and corresponding reduction in non-accidental deaths, due to proposed reduction in PM$_{2.5}$ concentrations for New Delhi.

<table>
<thead>
<tr>
<th>Proposed PM$_{2.5}$ limit (µg m$^{-3}$)</th>
<th>Reduction in non-accidental mortality (%)</th>
<th>Reduction in non-accidental deaths (per 100000 people)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>6.20</td>
<td>39</td>
</tr>
<tr>
<td>35</td>
<td>6.52</td>
<td>41</td>
</tr>
<tr>
<td>25</td>
<td>7.17</td>
<td>45</td>
</tr>
<tr>
<td>15</td>
<td>7.80</td>
<td>49</td>
</tr>
<tr>
<td>10</td>
<td>8.12</td>
<td>51</td>
</tr>
</tbody>
</table>

due to a pollutant exposure can be calculated by Eq. (4), using mortality rate (M).

$$PD_i = M \times \frac{ER_i}{ER_i + 1} \quad (4)$$

The excessive risk (ER$_i$), in Eq. (4), was calculated by Eq. (2), using $C_i$ as the averaged PM$_{2.5}$ concentration during the analysis period, and the $C_{\text{min},i}$ as the targeted PM$_{2.5}$ limit.

Decrease of PM$_{2.5}$ concentrations from current level to 10 µg m$^{-3}$ will result in a reduction of 8826 deaths in 2011. This is similar to the estimated deaths by (Guttikunda and Goel, 2013) due to PM$_{2.5}$ in New Delhi as 7350–16200 in the year 2010. Table 4 gives the projected reduction in non-accidental mortality and number of reduction in non-accidental deaths due to decrease in current PM$_{2.5}$ concentration to the levels suggested by INAAQS and WHO.

The averaged non-accidental mortality rate data for the year 2011 to 2014 was obtained from statistical handbooks of Delhi during those years (DES, 2014) as 0.625%.

Results indicate that, when the current levels are reduced to meet INAAQS annual limits of PM$_{2.5}$ i.e., 40 µg m$^{-3}$, the non-accidental mortality in New Delhi will be reduced by 6.20%, with 39 premature deaths avoided per 100000 people. Similarly, if the WHO levels of 35, 25, 15 and 10 µg m$^{-3}$ of PM$_{2.5}$ are met, the number of premature deaths per 100000 people will be reduced by 41, 45, 49 and 51, respectively.

SUMMARY AND CONCLUSIONS

This paper analyzed data collected at a busy traffic junction during 2011 to 2014 at New Delhi, to determine the most dangerous pollutant in New Delhi. AQI was used to identify the dominant pollutant while a health risk study quantified the deaths due to high concentration of the pollutant. Investigation showed that PM$_{2.5}$ was the dominant pollutant, during all the seasons, with dominant days being 24% higher in winter and pre-monsoon, than monsoon and post-monsoon. Moreover, significant differences in very poor and severe days were not observed on weekdays and weekends, with PM$_{2.5}$ being the dominant pollutant in all days. However, this conclusion might vary if PM$_{10}$ data is included in the analysis, and more studies are needed to explore this further. Additional investigation revealed that, this could be due to long range transport of air pollutants from different regions. This shows that air quality in New Delhi can be ameliorated only due to better policies in neighboring states.

The potential health risk associated with PM$_{2.5}$ was greater than CO and NO$_2$. The excessive risk associated with PM$_{2.5}$, NO$_2$ and CO were obtained as 0.57 (95% CI: 0.45, 0.69), 0.36 (95% CI: 0.24, 0.46), and 0.052 (95% CI: 0.046, 0.058), respectively. This is in agreement with the AQI method. Finally, the impact of reducing the current PM$_{2.5}$ concentrations, the most dominant pollutant in New Delhi was investigated. Results indicated that 39 and 41 premature deaths can be avoided per 100000 by bringing down the yearly averaged concentrations of PM$_{2.5}$ to the levels suggested by INAAQS and WHO, respectively.

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SUPPLEMENTARY MATERIAL

Supplementary data associated with this article can be found in the online version at http://www.aaqr.org.

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