Human health risks in national capital territory of Delhi due to air pollution

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ABSTRACT

This study evaluates the human health risks in Indian National Capital Territory of Delhi (NCT Delhi) in terms of mortality and morbidity due to air pollution. The spreadsheet model, Risk of Mortality/Morbidity due to Air Pollution (RI–MAP) was used to evaluate the direct health impacts of various criteria air pollutants present in various districts of NCT Delhi during the period 1991 to 2010. By adopting the World Health Organization (WHO) guideline concentrations for the air pollutants SO2, NO2 and total suspended particles (TSP), concentration–response relationship and a population attributable–risk proportion concept were employed. About 11 394, 3 912, 1 697 and 36 253 excess number of cases of total mortality, cardiovascular mortality, respiratory mortality and hospital admission of COPD respectively were observed for entire NCT Delhi in year 2000. However, within a one decade, in year 2010 these figures became 18 229, 6 374, 2 701 and 26 525. District–wise analysis shows that North West district is having the highest number of mortality and morbidity cases continuously after 2002, moreover least excess number of cases was observed for New Delhi district.

Keywords: Air Pollution, mortality, morbidity, human health, respiratory diseases

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1. Introduction

In the Indian National Capital Territory of Delhi (NCT Delhi), air pollution (e.g. PM, NOx, CO etc.) levels have exceeded most other cities in developing countries since the early 1990s (Gurjar et al.,2004; Nagpure, 2011). Scientific studies have indicated that the air pollution is mostly caused by combustion sources and causes human health impacts ranging from respiratory illnesses to death in urban areas (Mage et al., 1996; Gurjar et al., 2004; Madronich, 2006; Butler et al., 2008; Kumar et al., 2008; Gurjar et al., 2010; Kumar et al., 2011; Nagpure et al., 2011; Nagpure and Gurjar, 2012; Nagpure et al., 2013). Estimating the health impacts could help initiating international and national efforts to improve the air quality of NCT Delhi by implementing new policies and norms (Gurjar et al., 2008; Nagpure et al., 2010; Shukla et al., 2013; Babaei et al., 2014). To this end, Gurjar et al. (2008) calculated trace gas and particle emissions and ambient air quality in the Multi–Pollutant Index (MPI) to reveal air pollution impacts in the world’s 18 largest megacities. Likewise, Gurjar et al. (2010) used average values of ambient concentration of various air pollutants (e.g. SO2, PM, NOx) to estimate health risks in terms of mortality and morbidity in NCT Delhi. However, limitations of the Gurjar et al. (2010, 2012) studies were that they (1) did not address direct health impacts occurring annually due to particular pollutants, and (2) used average values of air pollutants for the entire city rather than at a district level, which produced general city–level results. Indeed, district level or area–wise ambient air quality monitoring and health risk modeling helps to identify least and most vulnerable areas with respect to air pollution within the megacity or state. Current study is the extension and expansion of our previous study (Gurjar et al., 2010). This study focuses on the quantification of various pollutants (SO2, NO2 and TSP) to assess human health impacts (mortality/morbidity) in various districts of NCT Delhi covering the areas of North–West, South, West, North–East, South–West, East, North, Central and New Delhi districts during the period 1991 to 2010 using the Risk of Mortality/ Morbidity due to Air Pollution (RI–MAP) model. A limitation to this study is the lack of analysis on (1) Synergistic effects of two or more pollutants, which is important because some pollutants can be more harmful when paired with others, and (2) other environmental and nutritional factors, which could cause greater sensitivity to poor air quality.

2. Material and Methods

2.1. Background of relative risk

In epidemiology, the relative risk (RR) is the probability of developing an illness caused by the exposure to pollutants (WHO, 2003; Rothman et al., 2008) The World Health Organization (WHO) has specified RR values and corresponding baseline incidences for different air pollutants as well as types of diseases associated with those values (Table 1). WHO (2003) relevant input data files in the air quality health impact assessment software AirQ2.2 (URL: https://euro.sharefile.com/download.aspx?id=7fd1822339468c8) was adopted for this study. The data is based on various previous studies (e.g., Poloniecki et al., 1997; Burnett et al., 1997; Spix et al., 1998; Sunyer, 1997; Touloumi, 1997; WHO, 2000).
Table 1. WHO default values of relative risk (per 10 μg/m³ increase of daily averages for SO₂, TSP and NO₂) corresponding to mortality

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Mortality/Morbidity</th>
<th>Relative Risk (RR)</th>
<th>Baseline Incidence Per 100,000 (I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₂</td>
<td>Total Mortality</td>
<td>1.004 (1.003–1.0048)</td>
<td>1,013</td>
</tr>
<tr>
<td></td>
<td>Cardiovascular Mortality</td>
<td>1.008 (1.002–1.012)</td>
<td>497</td>
</tr>
<tr>
<td></td>
<td>Respiratory Mortality</td>
<td>1.010 (1.006–1.014)</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>Hospital Admission COPD</td>
<td>1.0044 (1–1.011)</td>
<td>1,014</td>
</tr>
<tr>
<td>TSP</td>
<td>Total Mortality</td>
<td>1.003 (1.002–1.007)</td>
<td>1,013</td>
</tr>
<tr>
<td></td>
<td>Cardiovascular Mortality</td>
<td>1.002 (1–1.006)</td>
<td>497</td>
</tr>
<tr>
<td></td>
<td>Respiratory Mortality</td>
<td>1.008 (1.004–1.018)</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>Hospital Admissions COPD</td>
<td>1.0044 (1–1.0094)</td>
<td>1,014</td>
</tr>
<tr>
<td>NO₂</td>
<td>Total Mortality</td>
<td>1.002 (1–1.004)</td>
<td>497</td>
</tr>
<tr>
<td></td>
<td>Cardiovascular Mortality</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Respiratory Mortality</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The total, cardiovascular and respiratory mortality is the annual number of deaths in a given age group per the population in that age group (usually expressed per 100,000) due to exposure of air pollution. However, Hospital Admission COPD is the annual number of morbidity in a given age group per the population in that age group (usually expressed per 100,000) due to exposure of air pollution.

1 COPD: Chronic Obstructive Pulmonary Disease
2 Baseline Incidence per 100,000 is based on threshold limit given in WHO guideline
3 Lower and upper limits (range) of the 95% confidence interval of RR values

2.2. Concentration response equations

Estimation of health impacts from air pollutants is based on the population attributable–risk proportion (AP) concept (Douwes et al., 2002; Rothman et al., 2008). The assessment of mortalities in the Ri–MAP model is based on long term exposure (1 year) to the air pollutants (PM, NO₂, SO₂) whereas the morbidity is based on short term exposure (24 hours) (WHO, 1999; WHO, 2003). Assuming that there is a causal relationship between exposure and health outcomes with no major confounding effects, the AP can be attributed to pollutant exposure in a given population for a certain time period. This can be calculated using the following equation (WHO, 1999):

\[ AP = \frac{\sum[(RR(c) - 1) \times p(c)]}{\sum[AP(c) \times p(c)]} \]  

(1)

where, \( RR(c) \) is the changed relative risk for the health outcome in category \( c \) of exposure and \( p(c) \) is the proportion of the population in category \( c \) of exposure which could vary according to the degree of exposure in a different area. For example, industrial and residential areas have contrasting degrees of exposure, so health impacts from pollutants would vary. However, we must assume the same exposure in all districts throughout the city due to the lack of data availability.

\[ RR(c) = \frac{(C - T) \times (RR - 1) + 1}{(RR - 1) + 1} \]

(2)

where, \( C \) is the ambient air concentration of a pollutant, \( T \) is the threshold level of the pollutant as recommended by the WHO, and \( RR \) is the relative risk for the selected health outcome, which can be derived from the exposure–response function gathered from local epidemiological studies. We used the WHO default values because local studies for all districts were not available (Table 1).

Exposure of various populations to pollutants was measured using monitoring data from stations within NCT Delhi (see the Supporting Material, SM Figure S1). We used the arithmetic mean of selected concentrations for each time unit (daily or yearly). The average value was then used as indicator of the whole population’s exposure (i.e. one population – one value for a specified time period). For this purpose, we used daily concentrations data from 9 monitoring stations and taken the yearly average value of them.

Knowing (or often assuming) a certain baseline frequency (at threshold concentration value given by WHO guideline) of selected health outcomes (i.e., \( I \)) and the rate (or number of cases per unit population) attributed to the exposure in population (i.e., \( IE \)) can be calculated as (WHO, 1999):

\[ IE = i \times AP \]

(3)

For a population of given size \( N \), the \( IE \) can be converted to the estimated number of cases attributed to exposure (i.e., \( NE \)) using the following equation:

\[ NE = i \times N \]

(4)

Consequently, the frequency of the outcome in the population that is free from exposure (i.e., \( INE \)) can be estimated using the following equation:

\[ INE = i \times (1 - AP) \]

(5)

After deriving the \( RR \) at a certain level of pollution and the estimated incidence in non–exposed population, the excess incidence \( i.e., \Delta I(c) \) and excess number of cases \( i.e., \Delta N(c) \), respectively, at a certain category of exposure \( c \) can be calculated using the following equations:

\[ \Delta I(c) = (RR(c) - 1) \times p(c) \times INE \]

\[ \Delta N(c) = \Delta I(c) \times N \]

(6)

(7)

All aforementioned formulas are based on the assumption that the \( RR \) estimate is adjusted for any possible confounding variables. When the limits of the confidence interval for the \( RR \) estimate are used in the first equation, we obtain the corresponding AP range and the respective range for the number of cases in the population that can be attributed to pollutant exposure. The last equation is used to calculate the excess number of morbidity cases, which denotes the number of mortalities in the exposed population. In practice, however, the uncertainty of the impact (and the range of the estimated effect) is greater due to errors in exposure assessment and non–statistical uncertainty of the exposure–response function (WHO, 1999; WHO, 2003).
3. Results

Case study: NCT Delhi. To test and apply the above methodology, a case study has been performed to determine the inter–annual variation of the excess number of cases in various districts of the NCT Delhi. The WHO default values of RR are given for TSP. However, due to the lack of TSP data for various districts of Delhi, suspended particulate matter (SPM) concentration has been used as a surrogate for TSP. According to USEPA (U.S. EPA, 2014) TSP has a relatively coarse size range particulate matter however SPM is often used as a surrogate for TSP, is defined as PM with an aerodynamic diameter no greater than 30 μm.

The methodology described above depends mainly upon population and ambient air pollution concentration. Population data obtained from Census of India (2001, 2011). The ambient atmospheric concentrations of criteria pollutants, namely; SO₂, NO₂ and SPM, are the annual average concentration data (see the SM, Tables S1, S2, and S3) monitored and estimated by the Central Pollution Control Board (CPCB), Delhi, which has been taken from CPCB. In the previous study Gurjar et al. (2010) estimated health risk for entire NCT Delhi using average ambient concentration of nine monitoring stations. In this paper health risks have been calculated for various districts of the NCT Delhi using ambient air pollution concentration data of particular districts. There are 9 districts in NCT Delhi. Concentration data of respective monitoring station in each district is used for calculating district-wise health risk estimates. In absence of monitoring station data for any district, air quality data of the nearest monitoring station has been used for calculating health risk of that district. The results obtained from the above case study, using the proposed spreadsheet model (Ri–MAP) incorporating concentration response Equations (1) to (7), have been illustrated in Figures 1 to 4.

3.1. New Delhi

Figure 1a, 2a, 3a, and 4a illustrate the trend of the excess number of cases of total mortality, cardiovascular mortality, respiratory mortality and hospital admission due to Chronic Obstructive Pulmonary Disease (COPD) in the New Delhi district of NCT Delhi. In 1991, excess number of cases of total mortality was 81 followed by 152 in 1995, and 70 in 2000 were estimated for New Delhi. In 2005 the excess number of cases of total mortality was 101 while 126 in 2010 (Figure 1a). In case of cardiovascular mortality excess number of cases in 1991 was 27 followed by 51 in 1995, 23 in 2000, 35 in 2005 and 42 in 2010 (Figure 2a). The excess number of cases of respiratory mortality was 13 in 1991, 23 in 1995, 11 in 2000, 16 in 2005 and 20 in 2010 in New Delhi (Figure 3a). The excess number of cases of hospital admission COPD in 1991 was 116 and 215 in 1995 followed by 101 in 2000, 148 in 2005 and 179 in 2010 (Figure 4a). Results indicate that particulate matter is responsible for most of the excess number of cases of total mortality, cardiovascular mortality, respiratory mortality and hospital admission COPD in New Delhi area during the study period (1991–2010). However, few cases of total mortality have observed due to NOₓ pollution during 2005 (1.2%) and 2006 (2.6%).

3.2. Central Delhi

Figures 1b, 2b, 3b, and 4b show the excess number of cases of total, cardiovascular, respiratory mortality and hospital admission COPD cases in Central Delhi district of NCT Delhi. No specific trend is observed in the excess number of cases for total, cardiovascular, respiratory mortality and hospital admission COPD. The highest excess number of cases is observed in year 1991 for all mortality and morbidity because of higher concentration of pollutants in year 1991. Highest growths in mortality and morbidity have been observed in year 1993, 2006 and 2008. However decreasing trend is perceived between 1994 to 1997 and 2001 to 2005. Implementation of EURO norms and clean fuel technology (CNG) might be responsible for these trends. About 81 to 100% excess numbers of cases of total mortality have been observed due to SPM pollution while 0 to 4.7% cases noticed because of NOₓ pollution during the study period in Central Delhi Area. There is single evidence of excess numbers of cases (16.2%) of total mortality have been observed due to SO₂ in year 1991. Similarly about 86–100% and 82–100% of cases of respiratory mortality and hospital admission COPD have been noticed between 1991 and 2010 due to SPM although NOₓ is responsible for 0% and 0–15.4% of respiratory mortality and hospital admission COPD. The contribution of SO₂ has only been noticed in year 1991 for respiratory mortality (14%) and hospital admission COPD (9%).

3.3. North Delhi

The excess number of cases of mortalities and morbidity in North Delhi district is given in Figures 1c, 2c, 3c, and 4c. From 1991 to 1997 the excess numbers of cases of mortalities and morbidity have a negative slope. After that, from 1997 to 2002 an increasing trend is observed. In 2003, a sudden dip in the excess number of mortalities and morbidity is observed and 2003 to 2005 followed a similar trend. The highest excess number of cases all mortalities and morbidity were observed from 2006 to 2010 in North Delhi. The rising population and infrastructure growth in North Delhi might be the reason for these growths during recent years. Accountability of SPM pollution for excess number of cases of total mortality, cardiovascular mortality, respiratory mortality and hospital admission of COPD was 94–100%, 86–100%, 96–100% and 90–100% respectively in North Delhi region between 1991 and 2010. NOₓ is responsible for 0.1 to 3% and 0.5 to 10% of excess number of cases of total mortality and hospital admission of COPD. The contribution of SO₂ only observed in year 1991 for excess number of cases of total mortality (4.2%), cardiovascular mortality (7.7%), respiratory mortality (3.4%) and hospital admission of COPD (2.3%).

3.4. East Delhi

From 1991 to 1996 the excess number of cases of mortalities and morbidities were increasing while in 1997 a decrease in mortalities and morbidities are found in East Delhi (Figures 1d, 2d, 3d, and 4d). In 1991 the excess number of cases of total mortality was 683 followed by 1 128 in 1995, 779 in 2000, 932 in 2005 and 1 859 in 2010 (Figure 1d). In case of cardiovascular mortality, the excess number of cases in 1991 was 228 and in 1995 it was 381 followed by 260 in 2000, 317 in 2005 and 636 in 2010 (Figure 2d). About 107 numbers of cases of respiratory mortality was found in 1991 while in 1995 it was 169. In 2000, the excess number of cases of respiratory mortality was 124 followed by 147 in 2005 and 279 in 2010 (Figure 3d). In 1991 the excess number of hospital admission COPD was 972 followed by 1 586 in 1995, 1 115 in 2000, 1 357 in 2005 and 2 653 in 2010 (Figure 4d). SPM is responsible for the most of the excess number of cases of total mortality, cardiovascular mortality, respiratory mortality and hospital admission of COPD. Few evidence of excess number of cases of total mortality, cardiovascular mortality and hospital admission of COPD due to NOₓ have been observed in year 2004, 2005 and 2006. There is no excess number of cases of mortality and morbidity has been observed due to SO₂ pollution in East Delhi area.

3.5. South West Delhi

Until 1997 the rate of mortalities and morbidity were quite low in South Delhi. However about 31–37% of growth were observed between 1997 and 1998 in excess number of cases of total mortality, cardiovascular mortality, respiratory mortality and hospital admission of COPD. Highest number of excess number of cases of total mortality, cardiovascular mortality, respiratory mortality and hospital admission of COPD were observed in year 2010 (Figures 1e, 2e, 3e and 4e). The contribution of SPM for the excess number of cases of total mortality, cardiovascular mortality,
respiratory mortality and hospital admission of COPD in South Waste Delhi area was 96–100%, 87–100%, 99–100% and 90–100% respectively in South West Delhi during 1991–2010. Moreover the accountability of NOX was 0–2.5%, 0–10%, 0% and 0–9% for excess number of cases of total mortality, cardiovascular mortality, respiratory mortality and hospital admission of COPD respectively. Excess number of cases of total mortality, cardiovascular mortality, respiratory mortality and hospital admission of COPD were only observed in the year 1991 due to SO2 in South West Delhi.

**Figure 1.** Excess number of cases of Total Mortality in (a) New Delhi, (b) Delhi Central, (c) North Delhi, (d) East Delhi, (e) South West Delhi, (f) North East Delhi, (g) West Delhi, (h) South Delhi, (i) North West Delhi.
Figure 2. Excess number of cases of Cardiovascular Mortality in (a) New Delhi, (b) Delhi Central, (c) North Delhi, (d) East Delhi, (e) South West Delhi, (f) North East Delhi, (g) West Delhi, (h) South Delhi, (i) North West Delhi.
Figure 3. Excess number of cases of Respiratory Mortality in (a) New Delhi, (b) Delhi Central, (c) North Delhi, (d) East Delhi, (e) South West Delhi, (f) North East Delhi, (g) West Delhi, (h) South Delhi, (i) North West Delhi.
Figure 4. Excess number of cases of Hospital Admission COPD in Delhi Central in (a) New Delhi, (b) Delhi Central, (c) North Delhi, (d) East Delhi, (e) South West Delhi, (f) North East Delhi, (g) West Delhi, (h) South Delhi, (i) North West Delhi.
3.6. North East Delhi

The minimum excess number of cases of mortalities and morbidity is observed in the year 2005 while the maximum number is observed in 2010. In 1991, the excess number of cases of total mortality was 2 080 followed by 1 466 in 1995, 2 265 in 2000, 1 178 in 2005 and 2 949 in 2010 (Figure 1f). In the case of cardiovascular mortality, in 1991 the excess number of cases was 915 while in 1995 it was 557 followed by 801 in 2000, 403 in 2005, and 1 026 in 2010 (Figure 2f). In 1991 the excess number of cases of respiratory mortality was 280 and in 1995 it was 204 followed by 318 in 2000, 185 in 2005 and 430 in 2010 (Figure 3f). About 2 956 excess number of hospital admission of COPD cases was found in 1991 followed by 2 275 in 1995, 3 233 in 2000, 1 725 in 2005 and 4 228 in 2010 (Figure 4f). The reason is already discussed in an earlier paragraph of the New Delhi section, which states that high population of old age vehicles in certain year and their phasing out in another year might be responsible for the fluctuation in excess number of cases. SPM is responsible for 81–100%, 66–100%, 86–100% and 82–100% of excess number of cases of total mortality, cardiovascular mortality, respiratory mortality and hospital admission of COPD respectively. For NO₂, figures were 0–5%, 0–16% and 0–15% for excess number of cases of total mortality, cardiovascular mortality and hospital admission of COPD respectively. The evidence of SO₂ accountability for excess number of cases of total mortality, cardiovascular mortality, respiratory mortality and hospital admission of COPD were only observed in years 1991 and 1994.

3.7. West Delhi

In 1991 excess number of cases of total mortality was 1 487 while in 1995 it was 1 659 followed by 2 063 in 2000, 1 236 in 2005 and 2 505 in 2010 (Figure 1g). In the case of cardiovascular, the excess number of cases in 1991 was 510 followed by 566 in 1995, 704 in 2000, and 411 in 2005 and 842 in 2010 (Figure 2g). About 219 numbers of cases of respiratory mortality is found in 1991 which became 247 in 1995 followed by 306 in 2000, 1 999 in 2005 and 383 in 2010 (Figure 3g). In the case of hospital admission COPD, in 1991 the excess number of cases was 2 108 and in 1995 it was 2 343 followed by 2 919 in 2000, 1 775 in 2005 and 3 542 in 2010 (Figure 4g). The large population of old age vehicles might be responsible for the high excess number of cases, while their phasing out might attributed to the less excess number of cases. In West Delhi SPM is responsible for most of the excess number of cases of the mortality and morbidity.

3.8. South Delhi

Trend of excess number of cases of mortality and morbidity in South Delhi is increasing from 1991 to 2010 (Figures 1h, 2h, 3h, and 4h). In 1991, the excess number of cases of total mortality was 802 followed by 1 540 in 1995, 1 021 in 2000, 1 435 in 2005 and 2 794 in 2010 (Figure 1h). In the case of cardiovascular mortality, in 1991 the excess number of cases was 267 followed by 518 in 1995, 339 in 2000, 478 in 2005 and 947 in 2010 (Figure 2h). In respiratory mortality, the excess number of cases in 1991 was 128 while in 1995 it was 234, followed by 165 in 2000, 229 in 2005 and 424 in 2010 (Figure 3h). The excess number of cases of hospital admission COPD in 1991 was 1 149; in 1995 it was 2 174 followed by 1 468 in 2000, 2 055 in 2005 and 3 972 in 2010 (Figure 4h). In this district there is an overall increasing trend except a few dips, which might be due to the high density of vehicle population. In South Delhi the contributions of SPM was 96 to 100% for most of the excess number of cases of the mortality and morbidity and there is very less evidence have been observed due to NO₂ and SO₂.

3.9. North West Delhi

Figures 1i, 2i, 3i, and 4i show the excess number of cases of various mortality and morbidity in the North West Delhi district of NCT Delhi. Figures 1i, 2i, 3i, and 4i show that excess number of cases of mortality and morbidity are increasing from 1991 to 2010. The excess number of cases of total mortality in 1991 was 869 followed by 1 886 in 1995, 1 682 in 2000, 4 065 in 2005 and 4 035 in 2010 (Figure 1i). About 289 cases of cardiovascular mortality is found in year 1991 followed by 635 in 1995, 561 in 2000, 1 438 in 2005 and 1 524 in 2010 (Figure 2i). In the case of respiratory mortality, the excess number of cases in 1991 was 140 while in 1995 it was 286 followed by 265 in 2000, 582 in 2005 and 576 in 2010 (Figure 3i). Approximately 1 248 number of cases of hospital admission COPD is found in 1991 followed by 2 662 in 1995, 2 401 in 2000, 5 876 in 2005 and 6 305 in 2010 (Figure 4i). Till 2003, the contribution of SPM were 100% for most of the excess number of cases of the mortality and morbidity in North West Delhi where’s the share of NO₂ pollution for excess number of cases of the morbidity and morbidity were increased after 2003 in North West Delhi.

4. Resulting Uncertainties

The Ri–MAP model calculates average relative risks with the addition of lower and upper limits (i.e. range) for the 95% confidence interval based on the input parameters (Table 1). In each of the subsequent figures (Figures 1, 2, 3 and 4), solid bars show estimated values of excess number of cases and thin vertical lines show their lower and upper limits i.e. range for the 95% confidence interval. The uncertainties in the excess number of cases of total mortality, cardiovascular mortality, respiratory mortality and hospital admission of COPD are presented in Figures 1, 2, 3 and 4 in the form of error bars. It can be seen from the figures that cardiovascular mortality and hospital admission of COPD are having the highest uncertainties while respiratory mortality is having the least uncertainties in most of the districts of megacity Delhi.

5. Methodological Limitations

In reality, a population is exposed to a mixture of air pollutants present in the ambient air which may cause synergistic effects that is not considered by Ri–MAP. Ri–MAP is only able to estimate pollutant-specific impacts which may lead to erroneous results when the (under) estimated values are considered in absolute terms. Since daily average data were not available for all the districts, we have used annual average air quality concentrations of different districts whereas relative risk (RR) values pertain to increase in daily average concentrations. This may be a source of error in risk estimates. We are uncertain of the quality and accuracy of air quality data available through secondary literature, which we have used for health risk estimations.

6. Discussion

6.1. Total mortality

Dissimilar trends are observed in the excess number of mortality cases for various districts of Delhi. In 1991 the excess number of mortality in the New Delhi district of Delhi was 81 which is the least excess number of cases of mortality among all districts of Delhi (see the SM, Table S4). The highest excess number of cases is observed in North-East Delhi (2 080) districts in 1991 followed by West (1 487) and Central (1 258) districts of Delhi. In 1995 the highest excess number of cases of total mortality was found in North West (1 886) Delhi district followed by West (1 659) and South (1 540) districts. Total mortality is fluctuating with respect to concentration and increasing population. In 2000 the North East districts have the highest number (2 265) of total mortality cases while the second largest number of mortality rate is found in West (2 063) district followed by the South West (1 841) districts. The New Delhi district had the least number of total mortality rates among all districts. In 2005, the highest numbers of total mortality cases were found in North West districts followed...
by South and South West districts. From 2002 onwards, the excess number of mortality rate is continually higher in North West district because of higher concentration of pollutants and higher population. In 2010, the excess number of total mortality in North West district is 4 035, which is highest among all districts. In 2010 the North East district is in the second position with respect to total mortality rate followed by South Delhi district.

6.2. Respiratory mortality

In the case of respiratory mortality the highest excess number of cases is found in North East district (280) of Delhi in 1991 followed by West district (219) and Central districts (169), respectively (see the SM, Table S6). In 1995, the highest excess number of cases of respiratory mortality is found in North West district (286) followed by West Delhi (247) and South Delhi (234), while New Delhi had the least excess number of cases. In 2000, North–East district having highest number of respiratory cases followed by West and South West districts. After 2002 the North West Delhi is in top position until 2010 due to a higher concentration of pollutants.

6.3. Cardiovascular mortality

In the case of cardiovascular mortality, the North East district is in first position in 1991, followed by the West and Central districts (see the SM, Table S5). With 635 excess cases, the North West district is first for cardiovascular mortality during 1995 while the West district is in the second position followed by the North East district. Among all districts, New Delhi has the least number of respiratory mortality cases throughout the study period. In 2000, the excess number of cases of respiratory mortality was highest in the North East district followed by the West and South West district of Delhi. From 2002 to 2010 the North West district led the excess number of cases of respiratory mortality.

6.4. Hospital admissions due to chronic obstructive pulmonary disease

Hospital admission COPD cases are highest in the North East district of Delhi in 1991 followed by the West and Central district of Delhi (see the SM, Table S7). In 1995, the highest number of hospital admission COPD cases is observed in North West district while the West and North East district is in the second and third position, respectively. In year 2000, the excess number of cases of hospital admission of COPD is observed highest in the North East district followed by the West and South West district of NCT Delhi. From 2002 the North West district is in the top position for the highest excess number of cases of hospital admission of COPD until 2010.

7. Conclusion

Health risks (e.g. mortality/morbidity) have been estimated for various districts of megacity Delhi using Risk of Mortality/Morbidity due to Air Pollution (RI–MAP) model. About 8 945, 3 413, 1 302 and 12 809 excess number of cases of total mortality, cardiovascular mortality, respiratory mortality and hospital admission of COPD respectively were observed for NCT Delhi in the year 1991 although with 100% growth, these figures became 18 229, 6 374, 2 701 and 26 525 respectively in 2010. Impact of CNG implementation and phasing out program have clearly observed in districts like Delhi Central, North Delhi, East Delhi, South West Delhi, North East Delhi, and West Delhi where large transportation activities are present. It is observed that New Delhi district has the least excess number of cases of mortality/morbidity, possibly attributable to the lower population of New Delhi. It is found that higher ambient concentrations of SPM and NO₂ are responsible for excess number of mortality and morbidity in various districts of megacity Delhi.

Supporting Material Available

Ambient air concentrations of SO₂ observed at different monitoring stations of megacity Delhi from 1991 to 2010 (Table S1). Ambient air concentrations of NO₂ observed at different monitoring stations of megacity Delhi from 1991 to 2010 (Table S2). Ambient air concentrations of SPM in different monitoring stations of megacity Delhi from 1991 to 2010 (Table S3). Excess number of cases of Total mortality in (a) New Delhi, (b) Delhi Central, (c) North Delhi, (d) East Delhi, (e) South Delhi, (f) North East Delhi, (g) West Delhi, (h) South Delhi, (i) North West Delhi (Table S4), Excess number of cases of Cardiovascular Mortality in (a) New Delhi, (b) Delhi Central, (c) North Delhi, (d) East Delhi, (e) South Delhi, (f) North East Delhi, (g) West Delhi, (h) South Delhi, (i) North West Delhi (Table S5), Excess number of cases of Respiratory Mortality in (a) New Delhi, (b) Delhi Central, (c) North Delhi, (d) East Delhi, (e) South Delhi, (f) North East Delhi, (g) West Delhi, (h) South Delhi, (i) North West Delhi (Table S7), Location of ambient Air quality monitoring stations in Delhi (Figure S1). This information is available free of charge via the Internet at http://www.atmospolres.com.

References


