Air Quality and Health

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Abstract

This paper is written as part of the Harvard University Project, *Systems Analysis of Personal Transportation Needs in Emerging Market Countries*. It reviews the current literature on the health impact of ambient air pollution in India, with special emphasis on Delhi and provides recommendations for areas where future research could be directed.

High levels of total suspended particulate matter (TSP) in ambient air of Delhi - three times the annual national standard of 140µg/m³ - are a serious cause for concern. There is evidence of elevated rates of respiratory morbidity amongst those dwelling in highly polluted areas of Delhi, after adjusting for several confounders. Daily counts of emergency room visits for acute asthma, acute exacerbation of chronic obstructive airway disease (COAD) and acute coronary events are related to daily levels of pollutants, particularly TSP recorded a day earlier using time series approach. It is estimated that almost one fifth of the emergency room visits for these ailments in Delhi are attributable to particulate levels exceeding the national standards. Daily mortality from non-traumatic causes has been shown to be related to TSP levels in a time series analysis, however, the increase in mortality per 100 microgram/per cubic meter increase in Delhi is less as compared to similar effect noted from other parts of the world. Further, the excess mortality is noted in relatively younger age groups as well.

More studies are needed to confirm these observations and provide a concrete basis for policy decisions to improve air quality and public health in Delhi. Further studies are required on the adverse health effects of ozone, benzene, lead and other pollutants.
AIR QUALITY MONITORING IN DELHI

AIR QUALITY MONITORING BY CENTRAL POLLUTION CONTROL BOARD

The Central Pollution Control Board (CPCB), Government of India, as part of the National Ambient Air Quality Monitoring (NAAQM) Network, routinely monitors ambient air quality in Delhi. Six monitoring stations are established under this network in various parts of Delhi representing residential, industrial or mixed-use areas. They are located at Shahzada Bagh (North-West), Ashok Vihar (North-North West), Janakpuri (SouthWest), Shahdara (NorthEast), Nizamuddin (SouthEast) and Siri Fort (South). While Shahzada Bagh and Shahdara are classified as ‘industrial areas’, Nizamuddin as ‘mixed use area’ (residential-cum-commercial), the remaining are ‘residential’. However, with increasing developmental and commercial activities, the areas, which were earlier classified, as ‘Residential’ would be better described as ‘mixed use’ today. Data on air quality in these areas is available from 1987 onwards. In addition to the above six areas, the National Environmental Engineering Research Institute (NEERI) has established three monitoring stations viz. Najafgarh (West Delhi - Industrial), Netaji Nagar (South - Residential) and Town Hall (Central-North, Mixed). Data on air quality in these areas is available from 1989 onwards.

The Central Pollution Control Board has developed the currently applicable national ambient air quality standards. Developed in 1982, these were subsequently revised and notified in 1994. The standards are based on land use and other factors related to different areas. According to these criteria, areas were classified into industrial, mixed (with intense industrial activity), residential and sensitive (hill stations, national parks, national monuments and sanctuaries).

Regular monitoring by CPCB and NEERI is being done for only three criteria pollutants, viz. Suspended Particulate Matter (SPM), oxides of nitrogen (as NO\textsubscript{2}) and sulfur dioxide. The ambient levels of Respirable Particulate Matter (PM\textsubscript{10}, particles < 10 µm in diameter), lead and carbon monoxide were not being measured at any of the abovementioned nine stations till recently. The monitoring is done over twelve months of the year with a frequency of not less than once a week with a sampling time of 8 hours.

Most of the information available on air quality in Delhi pertains to the three criteria pollutants monitored by the CPCB (1,2). Some data is available on the PM\textsubscript{10} levels that have been monitored at a few locations recently and there are a few reports on levels of lead, ozone, volatile organic compounds that different agencies or workers have measured as specific projects. Keeping these limitations in view, the available information on air quality is presented in the following sections followed by a review of studies carried out to assess its impact on health.

Suspended Particulate Matter (SPM)/Total Suspended Particulates (TSP)

Fig 1 shows the mean±sd of the annual means from 1987-1996 of SPM in different areas being monitored. In increasing order, the values for the different areas were (figures in the order of mean±sd, 95% confidence intervals for the mean in µg/m\textsuperscript{3}) as follows:

- **Siri Fort**: 336.06±98.84, 316.58 to 355.57;
- **Ashok Vihar**: 351.72±131.06, 325.97 to 377.45;
- **Nizamuddin**: 358.93±98.66, 339.55 to 378.31;
- **Netaji Nagar**: 360.33±175.96, 317.08 to 403.58;
- **Janakpuri**: 369.75±98.62, 325.97 to 377.45;
- **Shahdara**: 374.05±112.21, 351.79 to 396.31;
- **Shahzada Bagh**: 414.02±137.87, 386.94 to 441.09;
- **Town Hall**: 511.94±212.30, 462.41 to 561.47;
- **Najafgarh**: 548.49±225.12, 488.76 to 608.22.

Analysis of variance revealed a significant difference between these means (F=20.22, p<0.00001). Inter-group comparisons with the Student-Neuman-Keuls test revealed that the levels at Najafgarh and Town Hall were significantly higher than all other areas though between themselves, these were not significantly different. The levels at Shahzada Bagh were significantly lower than at these two areas but were...
significantly higher than the levels at the remaining areas. Inter-group comparisons of levels in the remaining six areas did not reveal significant differences among these. It is notable that all the annual means were much higher than the NAAQS limit of $140 \mu g/m^3$ for residential areas. Thus, all the nine areas being monitored in Delhi have high degrees of SPM pollution. The pollution is the highest in Najafgarh and Town Hall areas, intermediate at Shahzada Bagh and lowest in the remaining six areas.

**Oxides of Nitrogen**

Fig. 2 shows the mean±sd of the annual means from 1987 to 1996 of oxides of nitrogen (as NO$_2$) in different areas being monitored. In increasing order, the values for the different areas were as follows:

- Siri Fort: 25.14±21.25, 23.81 to 26.47; Shahdara: 26.30±8.83, 24.56 to 28.04; Nizamuddin: 28.32±9.38, 26.47 to 30.17; Ashok Vihar: 29.21±8.97, 27.45 to 30.97; Janakpuri: 31.19±9.12, 29.39 to 32.97; Shahzada Bagh: 31.59±10.70, 29.48 to 33.70; Netaji Nagar: 39.91±20.59, 34.97 to 44.85; Najafgarh: 40.39±21.26, 35.32 to 45.45; Town Hall: 65.83±39.22, 56.74 to 74.91. Analysis of variance revealed a significant difference between these means ($F=46.37$, $p<0.00001$). Inter-group comparisons with the Student-Neuman-Keuls test revealed that the levels at Town Hall, Najafgarh and Netaji Nagar were significantly higher than all other areas. Among these three areas, the levels at Town Hall were significantly higher than the other two. The levels of NO$_2$ at Netaji Nagar were not significantly different from those at Najafgarh. The levels at the remaining six areas were not statistically different among themselves. It is notable that except at Town Hall, all the annual means were lower than the NAAQS limit of $60 \mu g/m^3$ for residential areas. Thus, nitrogen dioxide levels in Delhi air do not constitute a pollution problem except at Town Hall.

**Sulphur Dioxide**

Fig 3 shows the mean±sd of the annual means from 1987 to 1996 of SO$_2$ in different areas being monitored. In increasing order, the values for the different areas were as follows:

- Siri Fort: 11.40±4.93, 10.43 to 12.37; Janakpuri: 13.37±5.22, 12.35 to 14.40; Ashok Vihar: 14.25±6.73, 12.92 to 15.57; Nizamuddin: 14.30±5.47, 13.21 to 15.38; Netaji Nagar: 18.67±12.98, 15.50 to 21.83; Shahdara: 19.43±7.35, 17.97 to 20.88; Shahzada Bagh: 23.08±11.05, 20.89 to 25.28; Najafgarh: 26.68±14.79, 23.12 to 30.23; Town Hall: 36.25±25.99, 30.14 to 42.35. Analysis of variance revealed a significant difference between these means ($F=39.30$, $p<0.00001$). Inter-group comparisons with the Student-Neuman-Keuls test revealed that the levels of SO$_2$ at Najafgarh and Town Hall were significantly higher than all other areas. Between themselves, the levels of SO$_2$ were significantly greater at Town Hall than at Najafgarh. Inter-group comparisons of SO$_2$ levels in the remaining seven areas did not reveal significant differences among themselves. It is notable that all the annual means at all the areas were lower than the NAAQS annual limit of $60 \mu g/m^3$ for residential areas. Thus, none of the nine areas being monitored in Delhi have a pollution problem as far as SO$_2$ is concerned. Even in the areas with the highest SO$_2$ levels, the annual means remain well below the permissible limits.

**Trends in the Levels of Pollutants**

Tables 1 to 3 show the trends in annual means of Suspended Particulate Matter levels, oxides of nitrogen and sulfur dioxide (1989-1998) in different areas. While no clear trend is discernible, it appears that over the years, air quality has remained more or less unchanged with fluctuations in certain areas.
Apart from CPCB, a few other agencies and researchers have conducted studies to monitor specific pollutants in ambient air of Delhi. Ambient concentrations of carbon monoxide (CO), nitrogen oxides (NOx), sulfur dioxide (SO\textsubscript{2}), and total suspended particulates (TSP) were measured by Aneja et al (3) from January 1997 to November 1998 in the center of downtown [the Income Tax Office (ITO) located on Bahadur Shah Zafar Marg] New Delhi. The data consist of 24-h averages of SO\textsubscript{2}, NOx, and TSP as well as 8 and 24-h averages of CO. The measurements were made in an effort to characterize air pollution in the urban environment of New Delhi and assist in the development of an air quality index. The yearly average CO, NOx, SO\textsubscript{2}, and TSP concentrations for 1997 and 1998 were found to be 4810±2287 and 5772±2116 µg/cum, 83±35 and 64±22 µg/cum, 208 and 237 µg/cum, and 409±110 and 365±100 µg/cum, respectively. In general, the maximum CO, SO\textsubscript{2}, NOx, and TSP values occurred during the winter with minimum values occurring during the summer, which can be attributed to a combination of meteorological conditions and photochemical activity in the region. The ratio of CO/NOx (approximately 50) indicates that mobile sources are the predominant contributors for these two compounds in the urban air pollution problem in New Delhi. The ratio of SO\textsubscript{2}/NOx (approximately 0.6) indicates that point sources are contributing to SO\textsubscript{2} pollution in the city. The averaged background CO concentrations in New Delhi were also calculated (approximately 1939 µg/cum) which exceed those for Eastern USA (approximately 500 µg/cum). Further, all measured concentrations exceeded the US National Ambient Air Quality Standards (NAAQS) except for SO\textsubscript{2}. TSP was identified as exceeding the standard on the most frequent basis.

A study by Balachandran et al (4) examined the chemical composition of PM\textsubscript{10} particulates. An eight-stage Anderson impactor was used to separate the PM10 from other fractions with different aerodynamic behavior at three different area representative sites in Delhi from February to May 1998. PM\textsubscript{10} particulate are subdivided into two fractions, coarse (> 2.1-10 microns) and fine (< 2.1 microns). The concentrations of major heavy metals such as Pb, Zn, Cd, Ni, and Fe are determined by atomic absorption spectrophotometer. The average concentration of coarse fraction of PM\textsubscript{10} was found to be 68.3 ± 17 µg/cum while the fine fraction of PM\textsubscript{10} was 71.3 ± 15 µg/cum for Delhi. Metal concentration (except Fe) in fine fraction exceeded by a factor of up to 6, as compared to that in the coarse fraction. In order to identify the major sources of fine and coarse fraction of PM\textsubscript{10}, principle component analysis (PCA) was undertaken and three major sources were identified, namely vehicular emissions, industrial emission, and soil resuspension.

Lead

Ambient lead released with the exhaust gases remained a concern till 1994 when measures were initiated to bring down its amount in petrol from 0.56g/L to 0.15 g/L. In Delhi a high ambient air concentration (2604 ng/m\textsuperscript{3} at Azadpur intersection) in 24 hours, much in excess of the permissible limits of 1000 ng/m\textsuperscript{3} for residential areas, was observed in 1997. Some other locations also recorded a 24-hourly mean values exceeding 2000 ng/m\textsuperscript{3}. Out of the 19 locations surveyed, the particulate lead concentration exceeded the permissible safe limit at 6 locations including All India Institute of Medical Sciences. The permissible limit of 1000ng/m\textsuperscript{3} was exceeded in the residential areas, and at majority of locations. The highest values were found in the night from 12 am to 8 am. Use of unleaded petrol remains the best option. However, the lead accumulated in the soil from previous automobile emissions may still pose a risk by getting re-suspended in the air, either by the windy conditions or from the movement of vehicular traffic. Average concentration of Pb in atmospheric air particulates in different suburbs of Mumbai was studied by Tripathy et al (5) for almost a decade and its spatial and temporal profiles are
discussed in relation to emission sources. In general, the concentration of Pb in the entire residential suburban atmosphere is well below the Central Pollution Control Board (CPCB, 1994) prescribed limit of 1.5 µg/cum barring a few exceptions for some residential/industrial sites, such as those of Thane and Kurla scrap yards. The correlation between blood lead of children and air lead reveals that the blood Pb level in children could increase by 3.6 µg/dl for an incremental rise of 1.0 µg Pb m/cu m of air. The temporal profile of air Pb values indicates a decreasing trend in residential suburbs (Khar: 1984, 0.39 µg/cum; 1996, 0.17 µg/cum as well as in suburban residential areas with low traffic (Goregaon: 1984, 0.53 µg/cum; 1996, 0.30 µg/cum).

Volatile Organic Compounds

With the replacement of lead with alkylbenzenes in petrol, concern has been expressed about the levels of benzene in the urban air, which is monitored using a BTEX Analyzer (Benzene, Toluene, Ethyl benzene, o, m, p- Xylene) in Delhi and a few other places selectively. In Delhi, the highest concentrations of benzene ranging from 20 to 38 µg/cum were recorded in 1999 by the monitoring station near Income tax office (ITO). At other places the values ranged between 13 to 26 µg/cum. In Kanpur, the monthly average values between 7 to 41 µg/cum were recorded. The average monthly values were higher by a maximum factor of 2.4 at the monitoring locations when compared with the United Kingdom’s recommended annual average limit of 16 µg/cum. Like benzene, the polyaromatic hydrocarbons have also been monitored selectively. The measurements for benzo (a) pyrene B[a]P at six locations in Delhi indicate that the annual average ranged between 1.0 to 5.3 ng/cum during the period 1997 to 1999. The reference standard for B[a]P in ambient air is 10 ng/m³.

Varshney et al (6) monitored total volatile organic compounds (TVOCs) in the urban areas of Delhi at 13 sites. The levels of TVOCs were found to vary between 3 and 42 ppmv and exhibited wide temporal and seasonal variations. Peak levels coincided with peak traffic density. As these compounds contribute to the generation of toxic oxidants, a need for regular monitoring is recommended.

IMPACT OF INTERVENTIONS ON AIR QUALITY

In Delhi, some citywide interventions have been implemented since the year 2000 with a view to improve air quality and public health. In April 2000, old commercial vehicles were banned from plying on the roads, and buses, taxis and three-wheelers switched to CNG as a fuel in April 2001. The impact of these interventions in not known. There is some mixed evidence, especially with regard to levels of respirable suspended particulates (RSP) based on data monitored by the Central Pollution Control Board and Tata Energy Research Institute (7).

In the winter months (November 2000 – February 2001) following the ban on old commercial vehicles the concentration of TSP was higher than those during the winter before the ban (November 1999 – February 2000) at all locations monitored by CPCB. RSP levels were higher at the Lodi Road station operated by TERI but lower at the ITO crossing station operated by CPCB (Table 4).

Average levels of RSP in the two-month period April-May 2001 following the introduction of CNG, as compared to the levels during February-March 2001, increased at seven locations operated by TERI including the ITO crossing station. In contrast, at CPCB’s station at ITO crossing there was no change in RSP levels and at four other CPCB locations there was a decrease noted in RSP levels (Table 5).

Although it may be still to early to assess the impact of the interventions Delhi’s air quality, it is clear that there is an urgent need for more rigorous air quality monitoring and also
use of consistent methodologies in monitoring of critical pollutants in air by different agencies to enable meaningful comparison of data.

HEALTH EFFECTS OF AIR POLLUTION

Published studies in India have given conflicting evidence on the effects of air pollution on occurrence of respiratory symptoms and diseases. In some studies, no effect has been found on the prevalence of respiratory symptoms or lung function. In others, a variable effect has been shown with some age-sex groups having greater prevalence of one or more chronic symptom. Evidence to suggest that short-term and acute exposure to these pollutants leads to aggravation of symptoms and deterioration of lung function in patients with asthma and chronic obstructive lung disease is substantial and more definitive, however, there is considerable uncertainty regarding the long-term health effects of several air pollutants such as particulates, ozone, oxides of nitrogen and sulfur dioxide.

STUDIES IN DELHI

Respiratory Morbidity

Chhabra et al (8) carried out a study, the first of its kind, to assess the possible adverse effects of long-term exposure to air pollution in Delhi.

Subjects for the study were included from residential colonies, belonging to lower, middle and higher economic class, within 1 Km radius of the monitoring stations of the Central Pollution Control Board. In all, 4141 subjects were studied. Three pollution zones were considered according to the differences in particulates concentrations: Low: Below 400µg/m$^3$ (Shahdara, Janakpuri, Netaji Nagar, Nizamuddin, Ashok Vihar, Siri Fort); Medium: 400 to 500 µg/m$^3$ (Shahzada Bagh) and High: Above 500 µg/m$^3$ (Najafgarh, Town Hall). As there were fewer areas in medium and high pollution zones, these were combined into a single category of medium-high pollution for the purpose of comparison. There was a substantial contrast in air quality in these two zones, the SPM annual means in the medium-high pollution zone being 150-200µg/m$^3$ greater than the low pollution zones. It must be stated here that even the “low pollution zone” had very high particulate levels. The terms “low”, “medium” and “high” are relative and not absolute.

A respiratory symptoms questionnaire based on the widely used British Medical Research Council, American Thoracic Society and National Heart, and Blood and Lung Institute, USA questionnaires was administered to the subjects followed by a detailed enquiry of symptoms and examination by a Chest specialist to establish a clinical diagnosis in those found to have symptoms of respiratory disease. The health outcome (respiratory morbidity) was measured as follows: (1) Chronic respiratory symptoms: Chronic cough, Chronic phlegm, dyspnoea and wheezing; (2) Chronic Respiratory Airways Diseases: Chronic Bronchitis, Chronic Obstructive Pulmonary Disease (COPD) and Bronchial Asthma; (3) Lung Function in asymptomatic individuals.

Among males, in none of the economic groups the differences in the prevalence rates of chronic chest symptoms were statistically significant. Among female subjects, for chronic cough and chronic phlegm, the prevalence was significantly greater in the higher economic groups in residents of medium-high pollution zone as compared to the low pollution zone. In non-smoker males, when the occurrence of cough, chronic phlegm, dyspnoea and wheezing was considered by economic status and age group, no consistent pattern was evident with regard to their association with air pollution. Among non-smoking females however, in most age groups by economic status, cough and chronic phlegm were significantly more common in residents of medium-high pollution zones as compared to residents of low pollution zone. However, for
dyspnoea and wheezing, no consistent pattern was evident with regard to their association with air pollution. The prevalence of Chronic Obstructive Pulmonary Disease and Chronic Bronchitis was greater in male subjects in the middle and higher economic classes, and in female subjects in all the three economic classes in the medium-high pollution zone as compared to the low pollution zone. However, the differences were not statistically significant. The differences in prevalence rates of bronchial asthma between the pollution zones were not consistent or significant in either males or females.

While the differences in prevalence of chronic respiratory symptoms and airways diseases among residents of the two pollution zones were significant in some of the comparisons, much more striking was the definite demonstration of reduced lung function in asymptomatic non-smokers, both males and females, among those living in medium-high pollution zones. Our results showed that all the four spirometric parameters, FVC, FEV1, F25-75 and PEFR were significantly reduced in residents of medium-high pollution areas as compared to those in low pollution areas. As these comparisons were made among nonsmokers who were asymptomatic, the effects of disease and smoking did not interfere.

It was observed that the proportion of asymptomatic subjects with restrictive ventilatory impairment (i.e. FVC less than 70% predicted with a normal FEV1/FVC ratio) was significantly greater among residents of medium-high pollution areas as compared to residents of low pollution areas both among males and females. The number of subjects with such an abnormality was small, approximately 3%. Another significant observation on lung function abnormalities in asymptomatic subjects was the isolated (i.e. with a normal FEV1/FVC ratio) reduction in maximal mid-expiratory flow rates (F25-75). Subjects with such an abnormality were proportionately greater among residents of medium-high pollution areas for both males and females, the former being statistically significant. An isolated reduction in maximal mid-expiratory flow rates suggests early small airways disease.

The differences in the prevalence of some of the chronic respiratory symptoms among non-smokers in residents of high and low pollution areas reported in several studies including the present imply a definite adverse effect of air pollution. These suggest that hyper-secretion of mucus may be more common among residents of the more polluted areas. Poorer lung function, which was observed in the medium-high pollution areas, suggests a long-term deleterious effect on the lungs.

Smoking was the most important single independent determinant of cough, phlegm and dyspnoea in the present study. The risk of these symptoms and of COPD/chronic bronchitis increased with an increase in the intensity of smoking. No additive effect of smoking and air pollution was evident. Economic level was an important risk factor in the present study. The prevalence of chronic symptoms and diseases was substantially greater in subjects living in slums and low income housing areas. With an increase in the economic level, the prevalence of respiratory symptoms decreased significantly.

Pande et al (9) studied the relationship between the rates of hospitalization due to acute respiratory events (asthma and COPD exacerbations) and acute coronary events and ambient air quality. Daily counts of patients visiting the emergency room of the All India Institute of Medical Sciences (AIIMS, New Delhi) for acute asthma, acute exacerbation of chronic obstructive airway disease (COAD) and acute coronary event was obtained in a prospective manner from January 1997 to December 2000. Daily mean levels of ambient CO, NOX and SO2 were monitored along with temperature and humidity. Data was analyzed using one-day time lag for events of interest. Time series analysis was undertaken using Poisson regression and population averaged general estimation equation, correcting for auto-correlation, day of the week and the season. The ambient levels of pollutants exceeded the national air quality standards on most of the days, over the two-year period. Further emergency room visits for asthma, COAD and acute coronary events increased by 21.30%, 24.90% and 24.30% respectively on account of higher than acceptable levels of pollutants (Table 6). It was concluded that there is considerable burden of cardio-
respiratory diseases in Delhi due to high levels of ambient air pollution. Delhi has a number of
government hospitals, however, for the present study data was used from a single hospital (All
India Institute of Medical Sciences) as there is no central registry of hospital admissions, and the
outpatient records of other hospitals were not available. Considering the limitations in the
assessment of exposure and outcome variables, the findings should be taken as preliminary
observations. They are, however, of sufficient interest since no other reports are available from
Delhi.

A health survey to determine the adverse impact of vehicular pollution in Delhi was
undertaken in 1997 by Joshi (10). Based on area sampling, highly polluted areas (SPM
concentration, > 500 µg/cum) and rural areas with low pollution (assumed to be < 400 µg/cum)
were identified and numbered serially. Six pockets from each area were randomly selected. A
total of 1073 adults were chosen. A lifetime dose for each subject was computed based on
average air pollutant concentrations and daily time activity patterns. This was used as a surrogate
for individual life time exposure, which cannot be estimated with confidence in the event of
chronic exposure to a multitude of agents, as is the case with vehicular exhaust. A structured and
close-ended interview schedule was administered to the subjects followed by a physical
assessment by a trained physician.

The results showed that exposure to vehicular pollution in the city group (staying in high
pollution areas) were three-fold higher than that for rural population. There was no significant
difference in the two groups with regard to morbidity due to asthma, heart disease, and allergies.
The symptoms on the day of survey and in previous one year were significantly more in the urban
group. The urban residents experienced significantly more episodes of respiratory infections,
common colds, and febrile illness during past one year indicating the adverse health impact of a
higher dose of vehicular pollution. The frequency of respiratory infections in past one year in
asthmatics was significantly more than non-asthmatics. Rural subjects experienced significantly
more symptoms when coming into polluted areas. This paradoxical observation might be due to
the tolerance in urban group acquired due to frequent and regular exposure to vehicular pollution.
Exposure to vehicular pollution had a significant effect on diastolic blood pressure as well.

In a door-to-door survey, from October 1994 to March 1995, Akbar (11) studied 3010
adults drawn from middle-class background, and aged 25-45 years in Delhi in three geographical
areas, which differed in land-use pattern. The Suspended Particulate Matter (SPM) concentrations
monitored by the Central Pollution Control Board were used as indicators of exposure. Respirable
SPM (RSPM) was estimated in a sub-sample of the households. The long-term average SPM
concentrations in winters (1989-1993) in residential, commercial residential, and industrial areas
were 314 µg/cum, 337 µg/cum, and 420 µg/cum respectively. The mean RSPM concentrations in
the households in three areas were 215 µg/cum, 182 µg/cum, and 158 µg/cum, respectively in
residential, residential-commercial, and industrial areas respectively. The study concluded that
travel microenvironments have the highest RSPM exposure potential, followed by the ambient
environment, and indoor microenvironments. Three-wheelers and other “open” modes (e.g.
scooters and motorcycles) represent the mode of travel that is highest on the exposure ladder and
significantly different from buses and cars. Though the RSPM measurements were undertaken at
limited points, the study suggests that a rise in motor vehicle population and especially in the
number of “open” modes of travel is likely to lead to a large increase in commuters’ exposure to
high concentrations of traffic generated pollutants, consequently increasing their risk of
respiratory health damage significantly.

Mortality

Cropper et al (12) carried out a time series study of the impact of particulate air pollution on daily
mortality in Delhi. Mortality data from the New Delhi Municipal Corporation (NDMC) areas of
Delhi was analyzed that represents about 25% of total deaths in Delhi. A positive significant
relationship between particulate pollution and daily non-traumatic deaths, as well as deaths from respiratory/cardiovascular problems and for certain age groups was found. In general, the impacts were smaller than those estimated for other countries, where on average, a $100 \mu g/cu m$ increase in total particulates leads to a 6% increase in non-traumatic mortality. In Delhi, such an increase in particulates is associated with a 2.3% increase in deaths. This difference was attributed to the fact that in Delhi, a greater proportion of deaths occurs at younger ages and from causes not associated with air pollution than is the case in the U.S.

OTHER STUDIES IN INDIA

While studies on prevalence of asthma do not directly provide evidence linking it with air pollution, these are informative as data is valuable in making comparisons with other cities within and outside the country. A few studies have been carried out in the last few years.

Chowgule et al (13) applied epidemiologic surveillance tools, as a cooperating center of the European Community Respiratory Health Survey, to a randomly selected sample of Mumbai (Bombay) residents in 1992 through 1995. From a metropolitan population of over 10 million, they took a one-in-ten random sample from electoral rolls in a socially diverse residential district, and examined asthma symptoms in adults aged 20 to 44 yr. In Phase I, they interviewed 2,313 adults about symptoms, asthma diagnosis, and medications in the previous 12 months. In Phase II, family and smoking history, socioeconomic data, housing characteristics, serum IgE, allergy skin tests, spirometry, and methacholine challenge tests were obtained in a subset of 20% of those who had completed Phase I. House dust mite was the most common positive skin test (18% prevalence) and the only one of the nine applied that was significantly associated with asthma symptoms and physician-diagnosed asthma. Asthma prevalence was 3.5% by physician diagnosis, and 17% using a very broad definition including those with asymptomatic bronchial hyper-reactivity. Asthma prevalence was strongly associated with positive house dust mite skin test, family history of asthma, and total serum IgE.

To measure the prevalence of asthma in schoolchildren in Delhi and study the factors determining its occurrence, a questionnaire-based study was carried out in nine randomly selected schools in Delhi by Chhabra et al (14). The age range was 5 to 17 years. The questionnaires were distributed to all the children (n = 21,367) for answering by either parent. The key questions related to complaints of recurrent wheezing in the past, during the immediate last 1-year, and also wheezing exclusively induced by exercise or colds. In all, 19,456 questionnaires were received back (response rate 91%). Out of these, 18,955 were complete and analyzed. The prevalence of current asthma was 11.9% while past asthma was reported by 3.4% of children. Exclusive exercise-induced asthma was reported by 2.1% while that associated with colds by 2.4% of children. Boys had a significantly higher prevalence of current asthma as compared with girls (12.8% and 10.7%, respectively). Multiple logistic regression analysis showed that male sex, a positive family history of atopic disorders, and the presence of a smoker in the family were significant factors influencing the development of asthma while economic class, air pollution (total suspended particulates), and type of domestic kitchen fuel were not.

A few studies carried out in other parts of the country have looked into the adverse health effects of air pollution. A health study done by Kamat and Doshi (15) for 4 years in 4129 subjects from 3 urban (high, medium and low SO$_2$ levels) and a rural community showed a higher morbidity in subjects residing in areas with raised levels. Initially, the standardized prevalence (in percent) for the four areas respectively was: dyspnoea 7.3, 6, 3.2 and 5.5; chronic cough 5.1, 2.7, 1.7 and 3.3 and frequent colds 18.0, 20.8, 12.1 and 11 percent. The diagnosis of chronic bronchitis was made in 4.5, 4.5, 2.3 and 5.0 percent and cardiac disorders 6.8, 4.3, 8.2 and 2.7 percent in respective 4 areas. After 3 years, 55-60% of urban and 44% of rural subjects were reassessed. Initial lung functions were best in "urban low" area but in all urban areas, annual decline was larger than in rural subjects. A cross sectional study of 22,272 subjects residing in
four slum areas revealed generally higher morbidity with frequent colds, cough and dyspnoea. Daily health diaries maintained in 2232 subjects revealed high morbidity in 2 heavily polluted areas. Monthly trends correlated with ambient SO$_2$ and SPM. Ambient air pollution was associated with greater mortality (SMR) due to cardiorespiratory and malignant diseases. The major factors affecting morbidity were pollution, nutrition, occupation, smoking and age.

Awasthi et al (16) randomly selected a cohort of 664 children between the ages of 1 month to 4.5 yr from 28 slums (anganwadi centers) of Lucknow, north India. They were followed up fortnightly for six months. The outcomes assessed were presence of respiratory symptoms complex (RSC) at the time of interview and the number of days on which symptoms had occurred in the past week. Exposure to ambient air sulfur dioxide (SO$_2$), oxides of nitrogen (NOx) and suspended particulate matter (SPM) on the day of the interview or in the previous week was assessed by ambient air monitoring at 9 centers within the city. The cumulative incidence of RSC was 1.06 and the incidence density per 100 days of follow up was 1.63. All three pollutants were positively correlated with each other and negatively correlated with temperature. Ambient air SPM and SO$_2$ and cooking and heating fuels like dung cakes, wood, coal and kerosene and remaining indoors while the food was cooked were associated with increased incidence of RSC, increased duration of symptoms, or both. They concluded that to improve the respiratory health of preschool children, ambient air SPM and SO$_2$ levels should be kept as low as possible and mothers should be advised to keep children in another room while cooking.

Lahiri et al (17) investigated the pulmonary responses of 153 urban and 116 rural children in Calcutta and adjoining areas. A marked increase in respiratory symptoms (43% in urban and 14% in rural) and sputum alveolar macrophages was observed in urban children. Patel et al (18) recently reported the results of a study carried out in 297 children in the central Indian city of Nagpur. The study included children of six months to 6 years born between 1989 and 1995, a period coinciding with the use of leaded petrol. The environmental assessment included sampling for lead in air, tap water, mother’s milk, dairy milk, and other materials including house paint. For air sampling they used high volume samplers and collected 24-hour samples in a high traffic zone in the city center, a residential area, and at the periphery of the town. Venous samples were drawn and lead estimated using flameless atomic absorption spectrophotometry. Lead concentration in air was 0.065, 0.066 and 0.042 µg/cum, in winter, summer and monsoon seasons respectively. With CDC criteria (acceptable safe values < 10 µg/cum) as a reference, a total of 67.7% of screened children exceeded the level of concern. However, the study did not reveal an association between residential proximity to heavily trafficked roads and elevated Pb in contrast to previous studies. They could not rule out the possibility of misclassification and because of small number of children reporting such exposure, it is difficult to draw any definite inference.

CONCLUSIONS

Based on the above review of studies in Delhi on air quality and health, the following conclusions are drawn.

1. There has been growing concern over the problem of increasing ambient air pollution in Delhi over the past decade. The vehicular traffic has increased enormously contributing a major share to the burden of pollution. This has resulted in legislation setting deadlines for changeover to clean fuels and improved automobile technology. However, the impact of such interventions on public health cannot be assessed without rigorous monitoring systems in place. Monitoring of various pollutants in Delhi is still patchy and incomplete. There is an urgent need for regular monitoring of respirable SPM (as PM10 or PM5) and in a greater number of monitoring stations, which are the major culprits in causing health problems. More data is needed on pollution caused by ozone, lead, benzene and VOCs on
a regular basis. These could be obtained through a greater number of individual studies or by incorporating some of these pollutants in the CPCB monitoring schedule.

2. Although several studies have demonstrated adverse health effects of ambient air pollution in Delhi, the magnitude of this effect needs precise quantification. Long term longitudinal studies on large cohorts of subjects looking for association between the severity of air pollution and several postulated adverse health effects are required. For instance, no information is available on the association of air pollution with low-birth weight babies. Association between air pollution and adverse health effects is influenced by several potential and real confounders such as overcrowding, poverty, tobacco smoking, malnutrition, indoor air pollution and lack of access to health care and all these factors need to be carefully monitored and considered in future studies.

3. More rigorous studies are required to determine the association between air pollution and acute cardio-respiratory events requiring visit to emergency room using time series approach. Such type of studies may be best suited to a place like Delhi. However, accurate health information needs to be obtained from all government and private hospitals in Delhi for several years before meaningful estimates of increase in morbidity and mortality for a given increase in the levels of pollutants can be made. A large number of patients in Delhi do not reach any hospital despite significant morbidity or go to private practitioners so that the proportion of such deaths is not included in government records. This needs to be taken into account in the interpretation of data obtained from Municipal records.

4. No studies have been conducted to assess the relation between air pollution in Delhi and lung cancer or other malignancies. Studies worldwide have related particulate levels emitted from diesel exhaust with a high incidence of lung cancer. There is a need to undertake studies to examine the effect of air pollution on biomarkers for DNA in Delhi.

Despite several limitations of the reported studies on adverse health effects of air pollution in Delhi, there can be little doubt that the associations are of a causal nature and need to be taken seriously. Alongside future research to more accurately quantify the magnitude of the burden of disease due to air pollution, there is a need for policy-related decisions to be implemented with a view to curb the menace air pollution in Delhi and improve public health.

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List of tables and figures

1. Fig 1. Average of annual means (1987-1996) of SPM in different areas
2. Fig 2. Average of annual means (1987-1996) of Nitrogen Dioxide levels in different areas
3. Fig 3. Average of annual means (1987-1996) of Sulfur Dioxide levels in different areas
4. Table 1. Trends in annual means of Suspended Particulate Matter levels (1989-1998) in different areas
5. Table 2. Trends in annual means of Nitrogen Dioxide levels (1989-1998) in different areas
6. Table 3. Trends in annual means of Sulfur Dioxide levels (1989-1998) in different areas
7. Table 4: Comparing average levels of particulate matter during the winter after April 1, 2000 (ban on old commercial vehicles) with that during the winter prior to this date
8. Table 5. Comparing average levels of particulate matter during the two months after April 1, 2001 (CNG ruling) with that during the two months prior to this date
9. Table 6. Observed and expected daily events in 1997-98
Fig 1. Average of annual means (1987-1996) of SPM in different areas
(Dashed horizontal line indicates the permissible limits for annual means under the NAAQS)

Source: Central Pollution Control Board (NAAQMS series nos. 1,3,4,6,7,9)
Fig 2. Average of annual means (1987-1996) of Nitrogen Dioxide levels in different areas
(Dashed horizontal line indicates the permissible limits for annual means under the NAAQS)

Source: Central Pollution Control Board (NAAQMS series nos. 1,3,4,6,7,9)
Fig 3. **Average of annual means (1987-1996) of Sulfur Dioxide levels in different areas**

(Dashed horizontal line indicates the permissible limits for annual means under the NAAQS)

*Source: Central Pollution Control Board (NAAQMS series nos. 1,3,4,6,7,9)*
Table 1. Trends in annual means of Suspended Particulate Matter levels (1989-1998) in different areas

<table>
<thead>
<tr>
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<td>297.9±116.9</td>
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*Source: Central Pollution Control Board (NAAQMS series nos. 1,3,4,6,7,9 )*
Table 2. Trends in annual means of Nitrogen Dioxide levels (1989-1998) in different areas

<table>
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<td>Shahzada Bagh</td>
<td>21.41±7.33</td>
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<td>25.79±6.68</td>
<td>29.06±6.42</td>
<td>33.80±7.07</td>
<td>37.78±4.75</td>
<td>45.56±3.85</td>
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<td>32.1±1</td>
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<td>Town Hall</td>
<td>50.15±13.69</td>
<td>57.15±26.32</td>
<td>40.44±16.12</td>
<td>34.73±29.02</td>
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<td>77.17±33.71</td>
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Source: Central Pollution Control Board (NAAQMS series nos. 1,3,4,6,7,9)
Table 3. Trends in annual means of Sulfur Dioxide levels (1989-1998) in different areas

<table>
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<tr>
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<tbody>
<tr>
<td>Shahzada Bagh</td>
<td>9.98±7.50</td>
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<td>22.56±1.23</td>
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<td>32.20±11.26</td>
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<td>41.94±36.36</td>
<td>23.44±16.14</td>
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*Source: Central Pollution Control Board (NAAQMS series nos. 1,3,4,6,7,9 *)
### Table 4: Comparing average levels of particulate matter during the winter after April 1, 2000 (ban on old commercial vehicles) with that during the winter prior to this date

<table>
<thead>
<tr>
<th>Station</th>
<th>Total Suspended Particulate matter ($\mu g/m^3$) [Permissible limit = 200 $\mu g/m^3$]</th>
<th>Respirable Suspended Particulate matter ($\mu g/m^3$) [Permissible limit = 100 $\mu g/m^3$]</th>
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<tr>
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<tr>
<td>ITO Crossing (CPCB)</td>
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<td>555</td>
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<tr>
<td>Lodi Road (TERI)</td>
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NM = not measured
Table 5. Comparing average levels of particulate matter during the two months after April 1, 2001 (CNG ruling) with that during the two months prior to this date

<table>
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<tr>
<th>Station</th>
<th>Total Suspended Particulate matter (µg/m³) [Permissible limit = 200 µg/m³]</th>
<th>Respirable Suspended Particulate matter (µg/m³) [Permissible limit = 100µg/m³]</th>
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</table>

NM = Not measured
Table 6: Observed and expected daily (mean ± sd) events 1997-98

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<th>Disease</th>
<th>Observed</th>
<th>Expected*</th>
<th>Extra</th>
<th>%Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asthma</td>
<td>7.23 ± 7.82</td>
<td>5.96 ± 4.55</td>
<td>1.27 ± 4.93</td>
<td>21.30</td>
</tr>
<tr>
<td>COAD</td>
<td>4.37 ± 4.97</td>
<td>3.50 ± 2.48</td>
<td>0.87 ± 3.34</td>
<td>24.90</td>
</tr>
<tr>
<td>ACE</td>
<td>10.09 ± 7.09</td>
<td>8.11 ± 3.07</td>
<td>1.97 ± 5.70</td>
<td>24.30</td>
</tr>
<tr>
<td>Total</td>
<td>21.65 ± 17.65</td>
<td>17.44 ± 9.54</td>
<td>4.20 ± 11.38</td>
<td>24.10</td>
</tr>
</tbody>
</table>

*Calculated by assigning permissible upper level of CO and TSP in the regression model.

COAD - Chronic obstructive airways disease, ACE - acute coronary event.
Glossary

1. **Asthma**: A disease of the lungs characterized by symptoms of cough, breathlessness and wheezing
2. **Chronic obstructive airways disease (COAD) or Chronic Obstructive Pulmonary Disease (COPD)**: A disease of the lungs resembling asthma in symptomatology but occurring mainly among heavy smokers
3. **Acute coronary events**: Occurrence of symptoms of heart disease especially chest pain
4. **Chronic cough**: Cough occurring for more than 3 months in a year for at least 2 consecutive years
5. **Chronic phlegm**: Sputum (Phlegm) production occurring for more than 3 months in a year for at least 2 consecutive years
6. **Dyspnoea**: Breathlessness
7. **Wheeze**: Whistling sound in breathing
8. **Chronic Bronchitis**: Cough and sputum occurring for more than 3 months in a year for at least 2 consecutive years
9. **FVC**: A lung function test, defined as the maximum volume of air that can be exhaled from fully inflated lungs
10. **FEV<sub>1</sub>**: A lung function test, defined as the volume of air exhaled from fully inflated lungs in 1 second. It reflects the size of the airways.
11. **F<sub>25-75</sub>**: Average of expiratory flow rates over middle 50% of the FVC
12. **PEFR**: Highest flow rate achieved during a forceful exhalation
13. **Restrictive ventilatory impairment**: Impaired lung function due to reduction in lung size
14. **Serum IgE**: An antibody responsible for allergic reaction in asthma
15. **Allergy skin tests**: Tests carried out on skin to detect allergies
16. **Spirometry**: A technique used to carry out lung function tests
17. **Methacholine challenge tests**: A test to detect asthma-type responses of lungs
18. **Asymptomatic bronchial hyper-reactivity**: Airways resembling those of asthmatics but not having any symptoms
19. **Atopic disorders**: Allergic diseases