Research

Gender Disparity in Lung Function Abnormalities among a Population Exposed to Particulate Matter Concentration in Ambient Air in the National Capital Region, India

Chandrasekharan Nair
Kesavachandran1, Vipin Bihari1, Balram Singh Pангtey1, Ritu Kamal1, Amarnath Singh1, Anup Kumar Srivastava2

1 Epidemiology Division, CSIR-Indian Institute of Toxicology Research, Lucknow, India
2 Department of Community Medicine, Hind Institute of Medical Sciences, Lucknow, India

Corresponding Author:
Chandrasekharan Nair Kesavachandran
Principal Scientist, Epidemiology Division
CSIR-Indian Institute of Toxicology Research
Government of India, PB No 80, MG Marg, Lucknow, Utter Pradesh 226001
India
ckesavachandran@gmail.com

Introduction

Data collected globally between 2002 and 2010 to track air pollution trends in 189 megacities shows Indian cities among the top ranked for air pollution, with the highest ambient air pollution and smog on the Earth’s surface.1 A widely used health-relevant indicator of the air pollution mixture is particulate matter (PM).2,3 The Global Burden of Disease (GBD) 2010 report estimates over 2.1 million premature deaths and 52 million years of healthy life were lost in 2010 due to ambient air pollution.4 Among GBD-related risk factors, outdoor air pollution ranked 6th in South Asia (including India, Pakistan, Bangladesh and Sri Lanka), where it contributed to 712,000 deaths in 2010.4

Background. The World Health Organization (WHO) global air quality study shows that 27 Indian cities, including New Delhi, are among the one hundred cities with the worst air quality globally. The scope of airway obstruction cases among residents in locations with critical air pollution levels like particulate matter (PM) pollutants PM2.5 and PM10 has not been addressed in the National Capital region, India.

Objectives. The present cross-sectional study was undertaken to assess the forced expiratory volume in one second (FEV1) % predicted abnormalities among residents living in the National Capital Region, India with respect to their exposure to particulate matter pollutants (PM2.5, PM10) in ambient air.

Methods. Eight hundred and fifty-four residents, including 433 men and 421 women ranging in age from 18–70 years, living in the National Capital Region (NCR) of India participated in the study. Particulate matter concentrations in ambient air (PM2.5 and PM10) were monitored at 10 residential locations in the National Capital Region, India (New Okhla Industrial Development Authority (NOIDA) and Gurgaon). The lung function test (FEV1) was conducted using a spirometer.

Results. The Indian Air Quality Index showed either very poor or severe levels for PM2.5 at all study locations. A significant negative linear relationship was found between higher concentrations of PM2.5 and reduced FEV1 % predicted values (r = -0.8, p < 0.05). The prevalence of airway obstruction cases (79.6%, odds ratio 1.96, confidence interval 1.42–2.71) was higher (p<0.001) among female subjects compared to their male counterparts. Even though there was a significant decline in FEV1 % predicted among 80% of cases in women, only 19.24% cases were in the moderate category and 6.18% cases in the severe category. The severe category of FEV1 % predicted cases showed greater respiratory symptoms than the other two categories, which denotes higher risk among those in the severe category. The present study shows that obstruction cases increased from 1.97 to 7.40% and 2.73 to 14.93% in women, with a corresponding increase in PM2.5 and PM10, from the minimum to maximum concentration.

Conclusions. Since the women in this study were non-smokers, the PM in ambient air can be considered to be the major reason for the decline in lung function. The sources of PM pollutants in the study locations are large scale infrastructural development activities such as building and road construction activities. Narrowed lung airways can alter the airway caliber or resistance and flow rates proportional to the airway radius, especially in smaller airways. The present study suggests the need for policy makers and stake holders to take the necessary steps to identify PM sources and reduce the emissions of PM concentrations in ambient air.

Competing Interests. The authors declare no competing financial interests.

Keywords. Particulate matter, FEV1 % predicted, obstruction, women

particles with a mass median diameter of 10 microns or less (PM$_{10}$) and within a preset geometric standard deviation, the number of subjects with an forced vital capacity (FVC) predicted percentage of <70% increased from 5% to 8% in Switzerland. Previous cross-sectional studies have reported that air pollution can cause both retardation of lung function growth and acceleration of lung function decline.$^{5,6}$ The assessment of lung function is considered to be a significant predictor of respiratory diseases.$^{7}$

The World Health Organization (WHO) global air quality study shows that 27 Indian cities, including New Delhi, are among the top one hundred cities with the worst air quality.$^{8}$ The increased prevalence of respiratory symptoms and decrements in lung function among residents breathing polluted air has been previously reported.$^{9,10}$ Rapid deterioration of lung function was observed in a cohort study in Los Angeles due to long-term ambient exposure to air pollutants.$^{5}$ The American Thoracic Society (ATS) recommends that the severity of airflow obstruction should be based on the predicted percentage of the measured forced expiratory volume in one second (FEV$_1$).$^{11}$ Recent findings revealed greater respiratory symptoms among children residing in commercial areas compared to industrial and residential areas and found evidence for a positive association with PM$_{10}$ levels in the air.$^{12}$

Earlier Indian studies on the association of air pollutants with respiratory health problems focused on the effects of vehicular pollution among traffic policemen in Patiala, India; occupational exposure to carbon monoxide pollution levels in heavy traffic zones in Chandigarh, India; and lung function decline in healthy non-smoking male transport workers in Chennai, India due to exposure to

<table>
<thead>
<tr>
<th>Abbreviations</th>
<th>Description</th>
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<tbody>
<tr>
<td>AHSMOG</td>
<td>Adventist Health Air Pollution Study</td>
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<td>ANOVA</td>
<td>Analysis of variance</td>
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<td>ATS</td>
<td>American Thoracic Society</td>
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<td>CI</td>
<td>Confidence interval</td>
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<td>COPD</td>
<td>Chronic obstructive pulmonary disease</td>
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<td>CPCB</td>
<td>Central Pollution Control Board</td>
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<td>CSIR</td>
<td>Council of Scientific and Industrial Research</td>
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<td>ESCAPE</td>
<td>European Study of Cohorts for Air Pollution Effects</td>
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<td>FEV$_1$</td>
<td>Forced expiratory volume in one second</td>
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<td>FRM</td>
<td>Federal Reference Method</td>
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<td>FVC</td>
<td>Forced vital capacity</td>
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<td>GBD</td>
<td>Global burden of disease</td>
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<td>IAQI</td>
<td>Indian Air Quality Index</td>
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<tr>
<td>IHEC</td>
<td>Institutional Human Ethics Committee</td>
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<tr>
<td>IITR</td>
<td>Indian Institute of Toxicology Research</td>
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<tr>
<td>LPG</td>
<td>Liquified petroleum gas</td>
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<tr>
<td>M. nagar</td>
<td>Maharishi Nagar</td>
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<td>NAAQS</td>
<td>National Ambient Air Quality Standards</td>
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<td>NCR</td>
<td>National Capital Region</td>
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<td>NHANES</td>
<td>American National Health and Nutrition Examination Survey</td>
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<td>NICE</td>
<td>National Institute for Clinical Excellence</td>
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<td>NIST</td>
<td>National Institute of Standards and Technology</td>
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<td>NOIDA</td>
<td>New Okhla Industrial Development Authority</td>
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<tr>
<td>OR</td>
<td>Odds ratio</td>
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<tr>
<td>OSHA</td>
<td>Occupational Safety and Health Administration</td>
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<tr>
<td>PEFR</td>
<td>Peak expiratory flow rate</td>
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<tr>
<td>PM</td>
<td>Particulate matter</td>
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<tr>
<td>QA/QC</td>
<td>Quality assurance/quality control</td>
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<tr>
<td>SAE</td>
<td>Standardized air cleaner</td>
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<tr>
<td>SAPALDIA</td>
<td>Swiss Study on Air Pollution and Lung Disease in Adults</td>
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<tr>
<td>SEC</td>
<td>Socio-economic class</td>
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<tr>
<td>TEOM</td>
<td>Tapered element oscillating microbalance</td>
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<tr>
<td>USEPA</td>
<td>United States Environmental Protection Agency</td>
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<td>WHO</td>
<td>World Health Organization</td>
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health report with special emphasis on
gender among residents living in poor
ambient air quality conditions (PM\textsubscript{2.5},
PM\textsubscript{10}) in the NCR, India.

Methods

Study Locations
The National Capital Region covers
an area of about 33,578 square
kilometers and falls within the
territorial jurisdictions of four state
governments, namely the National
Capital Territory of Delhi, Haryana,
Uttar Pradesh, and Rajasthan. Urban
areas of the New Okhla Industrial
Development Authority (NOIDA)
in Uttar Pradesh and Gurgaon in the
Haryana area of the NCR were selected
as study locations. The main sources
of ambient air pollution in the study
locations are large-scale infrastructure
development activities, special
economic zone activities, construction
of roads and houses, moderate
traffic and agricultural dust. These
sources prompted us to identify study
locations in the NOIDA and Gurgaon
areas in the National Capital Region
in northern India.

The study area was extended to ten
different locations in the NCR in
order to determine the effect of the
different ambient air pollutants and
evaluate their potential interactions.\textsuperscript{21}
Bhangal, Hazipur, Maharishi Nagar
(M. Nagar), Baktiyarpur and Bisrakh
(all located in NOIDA, NCR, India),
Budhera, Chandu, Dhankot, Garhi,
and Sadhrana (all locations in
Gurgaon, NCR, India) were covered
in the present study. The geographical
locations in NOIDA and Gurgaon
are shown in Map 1 (\textit{see supplemental
material}) and Map 2 (\textit{see supplemental
material}), respectively. Nearby
states and locations of NOIDA and
Gurgaon are represented in Map 3 (\textit{see supplemental
material}).

Study Participants
Health camps were organized in each
location and the residents voluntarily
participated in the camps. Based
on the inclusion/exclusion criteria,
residents (study subjects) were
recruited at the health camps. The
inclusion criteria were subjects who
were 18 years of age and above who
lived and worked at the study locations
and did not have any previously
diagnosed communicable diseases.
All subjects who failed to clear the
inclusion criteria were excluded
from the study. We ensured that all
participants had a similar socio-
economic background and similar
age group distribution. All residents
were in the category of Lower Middle
(III) socio-economic class (SEC) as
per the Kuppuswamy socio-economic
criterion with an average monthly
income of about 7854.94 \pm 3081.04
Indian rupees. This criterion was
based on family income, education and
occupation.\textsuperscript{22} Of the total 854 study
subjects, 433 were men and 421 were
women.

All subjects participating in the
study worked and resided within
three kilometers of the air quality
sampling location. Subjects taking
medication or receiving treatment
for diseases were excluded from the
study. The study participants were
agricultural laborers, anganwadi
(child care) workers, beauticians,
hairdressers, small businessmen, shop
owners, salesmen, contract-manual
labourers, dairy and livestock workers,
gardeners, community health workers,
housewives, teachers and students.

Clearance for the study was obtained
from the Institutional Human Ethics
Committee (IHEC) of the Council
of Scientific and Industrial Research
(CSIR)-Indian Institute of Toxicology
Research (IITR), Government of India,
Lucknow. All participants provided
their written consent to participate
in the study after understanding the

A major difference of the present
study from other previous studies is
study location: ten semi-urbanized
locations (transitory phase from rural
to urban) in the National Capital
Region (NCR) compared to other
studies conducted at urban locations
such as Delhi and other capital cities.
Most of the earlier studies in India
have focused on PM\textsubscript{10}, whereas the
present study focused on fine particles
(PM\textsubscript{2.5} and PM\textsubscript{10}). The present study
also focused on lung function in adult
residents and the association with
ambient air pollution of fine particles
in residential areas, whereas previous
studies have focused on children
and outpatient/hospitalized patients.
Ambient air monitoring in other
studies, especially in hospital settings,
is mostly unrelated to the residential
areas of study subjects and this may
therefore interfere in the correlation
analysis between lung function
and PM. Hence, a cross-sectional
study was conducted to assess
FEV\textsubscript{1}, % predicted abnormalities and
respiratory symptoms among residents
living in the NCR with respect to
ambient air PM quality. To the best
of our knowledge, this is the first
adult population-based respiratory

fumes, dust and other motor exhaust
pollutants.\textsuperscript{13-15} Other studies in India
have focused on hospital admission
cases of respiratory disease and school
children with reduction in lung
function.\textsuperscript{6-18} These studies showed a
strong correlation between hospital
visits due to respiratory disease and
air pollutant emission strength in
the area of residence. Another study
found that women and children have
greater rates of respiratory problems
due to inadequate indoor ventilation
among the urban poor in Delhi.\textsuperscript{19} A
correlation between air pollution and
mortality was found in Delhi residents
and all-natural-cause mortality, and
morbidity was increased with higher
concentration of PM levels.\textsuperscript{20}
study details in the study brochure. The consent format, questionnaire, study data and study brochure were approved by the IHEC.

Survey and Questionnaire
Detailed information about the personal and family history, occupation, and symptoms experienced in the past month were collected through questionnaire (Appendix 1 is available as supplemental material) and administered by the interviewer. The questionnaire was prepared by the authors, tested in a pilot study and amended on the basis of the subjects’ reactions to the question form, wording and order.

Ambient Air Monitoring
Ambient air quality monitoring was conducted for eight hours per day at 10 randomly chosen locations. Micro-meteorological data were monitored along with ambient air quality. The monitoring was done on the same day as the health survey was conducted. Air monitoring for PM$_{2.5}$ and PM$_1$ was carried out using a real-time, automated ambient air monitoring instrument (HAZDUST, Model: SKC EPAM-5000, PA 15330) at all study locations.

The EPAM-5000 is an innovative light scattering nephelometer and filter gravimetric air sampler combined in one portable compact and lightweight design. The unique design allows the air quality investigator to collect size selective particulate matter using two proven techniques: light scattering and filter gravimetric. Size selective sampling is achieved by a single jet impactor for PM$_{2.5}$ and PM$_1$ with an Occupational Safety and Health Administration (OSHA) approved respirable cyclone. It has a unique aerodynamic particle sizing real time sensor and in line Federal Reference Method (FRM) 47-mm filter cassette which allows concurrent gravimetric samplings. The specifications for the EPAM-5000 were as follows; calibration: gravimetric reference National Institute of Standards and Technology (NIST) traceable standardized air cleaner (SAE) test dust, fine ISO12103-1; accuracy: +10% to filter gravimetric SAE fine test dust and sampling flow rate- 1.0-5.0 litres/minute. The EPAM 5000 has the proper size selection features for measuring the three respiratory regions (inhalable, thoracic and respirable) that are applicable to both the United States Environmental Protection Agency (USEPA) and OSHA standards. The EPAM 5000 has a high correlation to tapered element oscillating microbalance (TEOM) monitor USEPA equivalency method designation EQPM-1090-079, as per the EPAM-5000 manual. The method proposed by the Central Pollution Control Board (CPCB) for measurement of PM$_{2.5}$ was gravimetric or TOEM or beta attenuation. The Haz-Dust follows the gravimetric method and is well correlated with measurements in the TOEM monitor for PM$_{2.5}$ measurement.

Quality assurance/quality control (QA/QC) procedures were maintained as per the instruction manual of the instrument. Manual-Zero sets the measurement baseline of the EPAM-5000 to zero µg/m$^3$. The Manual-Zero check was performed prior to beginning a new set of measurements. A flow meter was used to assess and ensure a flow rate in the instrument of 4 L/minute before air monitoring. The monitoring exercise was conducted at a height of 10 m from the ground and the instrument was placed on the roof of nearby houses. The criteria for the selection of air monitoring site at each study location was 200 m away from traffic intersections. The study was conducted during the summer season from July to September from 2008 to 2010 with the same monitor. Table 1 shows the Indian Air Quality Index (IAQI) proposed by the CPCB, India (2014) to indicate the extent to which ambient air quality has exceeded the regulatory limits. No regulatory body in India has proposed an IAQI for PM$_1$.

### Table 1 — Indian Air Quality Index Proposed by the CPCB (2014)$^{14}$

<table>
<thead>
<tr>
<th>PM$_{2.5}$ concentration</th>
<th>Indian Air Quality Index (IAQI)</th>
</tr>
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<tbody>
<tr>
<td>0–30 µg/m$^3$</td>
<td>Good</td>
</tr>
<tr>
<td>31–60 µg/m$^3$</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>61–90 µg/m$^3$</td>
<td>Moderately polluted</td>
</tr>
<tr>
<td>91–120 µg/m$^3$</td>
<td>Poor</td>
</tr>
<tr>
<td>121–250 µg/m$^3$</td>
<td>Very poor</td>
</tr>
<tr>
<td>250+</td>
<td>Severe</td>
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</tbody>
</table>

Spirometry
The PiKo-1 (Ferraris Cardiorespiratory, Louisville, USA) spirometer was used to measure FEV$_1$. The results were interpreted using the predicted reference equation for Indians. The lung function test was repeated three times in one subject for reliability and a maximum variation
of <5% was considered acceptable. The severity status for obstructive lung function abnormality was assessed using FEV\(_1\)% predicted as per National Institute for Clinical Excellence (NICE) 2004 guidelines, which was classified as mild airflow obstruction (50–80% predicted), moderate airflow obstruction (30–49% predicted), or severe airflow obstruction (<29% predicted). The predicted norms for an Indian population were used to calculate FEV\(_1\)% predicted for the study subjects.

### Statistical Analysis

Data recorded on a predesigned proforma were entered in a Microsoft Excel spreadsheet. All entries were double-checked for possible typing errors. Descriptive statistics (mean, standard deviation) were used to compare the quantitative parameters (age, height, weight). One-way analysis of variance (ANOVA) was used to check for significant differences in age, height and weight of the study subjects in various air sampling sites. The prevalence of self-reported respiratory symptoms was calculated with odds ratio (OR) and 95% confidence interval (CI). Linear regression analysis was carried out with PM parameters (PM\(_{2.5}\), PM\(_{1}\)) as independent variables and FEV\(_1\)% predicted as a dependent variable. Bivariate analysis was used.
to identify the potential confounders among the variables. Multivariate logistic regression analysis was performed for the calculation of an OR after adjusting for the confounders and was found to be significant in the bivariate analysis.

A regression model was used to predict the prevalence percentage for respiratory obstruction corresponding to various PM concentrations. The criteria of statistical significance was set at p < 0.05. All calculations were performed using STATA IC 13 and SPSS Statistics Version 20.

**Results**

**Physical Characteristics**

Table 2 shows the mean age, height, and weight of the residents living in different locations. No significant difference in age was observed between the locations, whereas a significant difference (p < 0.001) was found for height and weight.

<table>
<thead>
<tr>
<th><strong>Air sampling sites</strong></th>
<th>PM$_{10}$ (µg/m$^3$)</th>
<th>PM$_{2.5}$ (µg/m$^3$)</th>
<th>IAQI</th>
<th>Responders (n)</th>
<th>FEV$_1$ &lt; 80% Predicted</th>
<th>FEV$_1$ &gt; 80% Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Noida Region</strong></td>
<td></td>
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</tr>
<tr>
<td>Baktiyarpur</td>
<td>282</td>
<td>246</td>
<td>Severe</td>
<td>108</td>
<td>85 (78.7)</td>
<td>23 (21.3)</td>
</tr>
<tr>
<td>Bhangal</td>
<td>315</td>
<td>164</td>
<td>Severe</td>
<td>106</td>
<td>72 (67.9)</td>
<td>34 (32.1)</td>
</tr>
<tr>
<td>Bisrakh</td>
<td>160</td>
<td>130</td>
<td>Severe</td>
<td>67</td>
<td>50 (74.6)</td>
<td>17 (25.4)</td>
</tr>
<tr>
<td>Hazipur</td>
<td>295</td>
<td>116</td>
<td>Severe</td>
<td>124</td>
<td>92 (74.2)</td>
<td>32 (25.8)</td>
</tr>
<tr>
<td>Maharishi Nagar</td>
<td>159</td>
<td>12</td>
<td>Very poor</td>
<td>72</td>
<td>37 (51.4)</td>
<td>35 (48.6)</td>
</tr>
<tr>
<td><strong>Gurgaon Region</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Budhera</td>
<td>227</td>
<td>56</td>
<td>Severe</td>
<td>79</td>
<td>59 (74.7)</td>
<td>20 (25.3)</td>
</tr>
<tr>
<td>Chandu</td>
<td>132</td>
<td>96</td>
<td>Very poor</td>
<td>52</td>
<td>39 (75.0)</td>
<td>13 (25.0)</td>
</tr>
<tr>
<td>Dhankot</td>
<td>323</td>
<td>179</td>
<td>Severe</td>
<td>66</td>
<td>53 (80.3)</td>
<td>13 (19.7)</td>
</tr>
<tr>
<td>Garhi</td>
<td>227</td>
<td>35</td>
<td>Severe</td>
<td>127</td>
<td>96 (75.6)</td>
<td>31 (24.4)</td>
</tr>
<tr>
<td>Sadhrana</td>
<td>295</td>
<td>178</td>
<td>Severe</td>
<td>53</td>
<td>40 (75.5)</td>
<td>13 (24.5)</td>
</tr>
</tbody>
</table>

**Table 3 — Air Quality at Different Locations in NCR and its Association with FEV$_1$ Among Residents**

Air Quality at Study Locations and its Associated FEV$_1$ % Predicted Outcomes in Residents

The temperature varied from 24–40ºC, with an average of 31ºC, while average humidity and wind speed were found to be 58% and 12 km/hr, respectively. On the other hand, an average temperature of 30ºC was observed in the Gurgaon study locations without any marked differences in average humidity (55%) and wind speed (12 km/hr). No rainfall was observed during the study period at either location.

All study locations showed concentrations exceeding the National Ambient Air Quality Standards (NAAQS) limit in India. As per the IAQI, residents living in locations such as Chandu and Maharishi Nagar fell in the category of very poor air quality as per IAQI norms, while locations like Budhera, Hazipur, Baktiyarpur, Bhangal, Bisrakh, Garhi, Dhankot, and Sadhranafell under the severe criteria of IAQI (Table 3). The prevalence of <80% FEV$_1$ % predicted was 67.9–80.3% for residents living in conditions classified as severe as per the IAQI, which denotes airway obstruction.

Similarly, 51.4–75% of residents with FEV$_1$ % predicted <80% live in very poor conditions for all group categories as per the IAQI (Table 3).

The highest PM$_{2.5}$ concentrations (323 µg/m$^3$) among all study locations and highest prevalence (80.3%) of airway obstruction (FEV$_1$ % predicted <80%)
among residents at all study locations was observed at Dhankot (Table 3). The present study shows that the prevalence of FEV$_1$ % <80% predicted was higher among residents living at locations with higher PM concentrations, especially at Bhaktiyarpur (78.7%), Garhi (75.6%), Sadhrana (75.5%) and Chandu (75%) (Table 3).

Respiratory Symptoms with Respect to FEV$_1$ % Predicted

A higher prevalence of cough symptoms was observed in Bhangal and Sadhrana. Cold symptoms were more or less the same at all locations, while more complaints of breathlessness were observed in Bhaktiyarpur and Garhi; productive cough was more common among residents of Chandu and Maharishi Nagar, and the prevalence of combined symptoms such as cough and cold/cough with breathlessness were higher among residents of Dhankot (Table 4). The overall prevalence of respiratory symptoms among residents was higher for residents of Bhaktiyarpur (24.1%), followed by Bhangal (23.6%), and Garhi (23.6%). All of the above three locations fell into the severe IAQI category (Table 4).

In the FEV$_1$ % predicted >80% and 50–79% categories, the prevalence of respiratory symptoms was comparatively lower than the prevalence of residents without respiratory ailments (Table 5). An increase in the frequency of prevalence with respect to respiratory illnesses was also observed among residents in the 30–49% and <29% categories of

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<table>
<thead>
<tr>
<th>Air sampling sites</th>
<th>Cough n (%)</th>
<th>Cold n (%)</th>
<th>Breathlessness n (%)</th>
<th>Productive Cough n (%)</th>
<th>Cough &amp; Cold n (%)</th>
<th>Cough with Breathlessness n (%)</th>
<th>Overall Prevalence (95% CI)</th>
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<tbody>
<tr>
<td>Noida Region</td>
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<td></td>
</tr>
<tr>
<td>Baktiyarpur (n=108)</td>
<td>9 (8.3)</td>
<td>2 (1.8)</td>
<td>11 (10.2)</td>
<td>0 (0.0)</td>
<td>1 (0.9)</td>
<td>3 (2.8)</td>
<td>24.1 (15.5–32.6)</td>
</tr>
<tr>
<td>Bhangal (n=106)</td>
<td>14 (13.2)</td>
<td>1 (0.9)</td>
<td>6 (5.7)</td>
<td>1 (0.9)</td>
<td>2 (1.9)</td>
<td>1 (0.9)</td>
<td>23.6 (15.0–32.1)</td>
</tr>
<tr>
<td>Bisrakh (n=67)</td>
<td>5 (7.5)</td>
<td>1 (1.5)</td>
<td>2 (3.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>1 (1.5)</td>
<td>13.4 (4.5–22.3)</td>
</tr>
<tr>
<td>Hazipur (n=124)</td>
<td>8 (6.5)</td>
<td>2 (1.6)</td>
<td>8 (6.5)</td>
<td>1 (0.8)</td>
<td>0 (0.0)</td>
<td>2 (1.6)</td>
<td>16.9 (9.9–23.9)</td>
</tr>
<tr>
<td>Maharishi Nagar (n=72)</td>
<td>6 (8.3)</td>
<td>0 (0.0)</td>
<td>3 (4.2)</td>
<td>2 (2.8)</td>
<td>0 (0.0)</td>
<td>2 (2.8)</td>
<td>18.1 (8.5–27.6)</td>
</tr>
<tr>
<td>Gurgaon Region</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chandu (n=52)</td>
<td>4 (7.7)</td>
<td>1 (1.9)</td>
<td>4 (7.7)</td>
<td>2 (3.8)</td>
<td>0 (0.0)</td>
<td>2 (3.8)</td>
<td>25.0 (12.3–37.7)</td>
</tr>
<tr>
<td>Budhera (n=79)</td>
<td>8 (10.1)</td>
<td>0 (0.0)</td>
<td>3 (3.8)</td>
<td>1 (1.3)</td>
<td>1 (1.3)</td>
<td>2 (2.5)</td>
<td>19.0 (9.7–28.3)</td>
</tr>
<tr>
<td>Garhi (n=127)</td>
<td>10 (7.9)</td>
<td>0 (0.0)</td>
<td>11 (8.7)</td>
<td>4 (3.1)</td>
<td>4 (3.1)</td>
<td>1 (0.8)</td>
<td>23.6 (15.8–31.4)</td>
</tr>
<tr>
<td>Dhankot (n=66)</td>
<td>8 (12.1)</td>
<td>1 (1.5)</td>
<td>4 (6.1)</td>
<td>0 (0.0)</td>
<td>1 (1.5)</td>
<td>4 (6.1)</td>
<td>27.3 (15.8–38.8)</td>
</tr>
<tr>
<td>Sadhrana (n=53)</td>
<td>7 (13.2)</td>
<td>1 (1.9)</td>
<td>1 (1.9)</td>
<td>1 (1.9)</td>
<td>1 (1.9)</td>
<td>1 (1.9)</td>
<td>22.6 (10.4–34.8)</td>
</tr>
</tbody>
</table>
```

Table 4 — Self-Reported Respiratory Complaints Among Residents
FEV$_1$ % predicted, compared to the > 80% and 50–79% categories (Table 5).

Relationship of PM Concentration and FEV$_1$ % Predicted
A significant negative linear relationship was observed between higher PM$_1$ concentrations and FEV$_1$ % < 80% predicted (Figure 1). However, the correlation between PM$_{2.5}$ concentrations and FEV$_1$ % <80% predicted did not attain statistical significance at the 5% level (Figure 1).

FEV$_1$ % Predicted in Relation to Age, Sex, Smoking Status and Respiratory Symptoms
Table 6 shows adjusted FEV$_1$ % predicted for age, sex, smoking status and respiratory symptoms among residents of the study locations. A higher prevalence of obstructive respiratory abnormalities was

<table>
<thead>
<tr>
<th>FEV$_1$ Severity Stages, n (%)</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal: &gt; 80% predicted, n = 231 (27.0)</td>
<td></td>
</tr>
<tr>
<td>with respiratory symptoms</td>
<td>40 (17.3)</td>
</tr>
<tr>
<td>without respiratory symptoms</td>
<td>191 (82.7)</td>
</tr>
<tr>
<td>Mild: 50%–79% predicted, n = 426 (49.9)</td>
<td></td>
</tr>
<tr>
<td>with respiratory symptoms</td>
<td>82 (19.2)</td>
</tr>
<tr>
<td>without respiratory symptoms</td>
<td>344 (80.8)</td>
</tr>
<tr>
<td>Moderate: 30%–49% predicted, n = 146 (17.1)</td>
<td></td>
</tr>
<tr>
<td>with respiratory symptoms</td>
<td>33 (22.6)</td>
</tr>
<tr>
<td>without respiratory symptoms</td>
<td>113 (77.4)</td>
</tr>
<tr>
<td>Severe: &lt; 29% predicted, n = 51 (6.0)</td>
<td></td>
</tr>
<tr>
<td>with respiratory symptoms</td>
<td>11 (21.6)</td>
</tr>
<tr>
<td>without respiratory symptoms</td>
<td>40 (78.4)</td>
</tr>
</tbody>
</table>

Table 5 — Respiratory Symptoms with Respect to FEV$_1$ % Predicted
observed for women compared to men (p < 0.001) and in the age group >40 years compared to <40 years. Although a higher prevalence of FEV\textsubscript{1} % <80% predicted was observed among women, out of these 80% of cases, 19.24% were moderate and 6.18% were severe. Individual effects for the age group >40 years (OR 1.31, 95% CI 0.93–1.84), women (OR 1.96, 95% CI; 1.42–2.71), smoking status (OR, 1.15, 95% CI; 0.93–1.84), women (OR, 1.96, 95% CI; 0.80–1.83) were observed in the <80% category FEV\textsubscript{1} % predicted among the study subjects.

### Prevalence Percentage of FEV\textsubscript{1} % Predicted Cases with PM Concentration

The higher prevalence of FEV\textsubscript{1} % <80% predicted cases among women with an increase in PM\textsubscript{1} concentrations (PM\textsubscript{1} and PM\textsubscript{25}) from the minimum to different percentile values (25th, 50th, 75th, and maximum) are shown in Table 7. The increase in FEV\textsubscript{1} % <80% predicted cases with PM\textsubscript{1} from the minimum to the maximum concentration were 1.97% and 7.40%, respectively. The increase in FEV\textsubscript{1} % predicted cases with PM\textsubscript{25} from the minimum to the maximum concentration was 2.73 and 14.93%, respectively.

### Discussion

In the present study, we analyzed air quality and lung function of residents in different parts of the NCR, India. FEV\textsubscript{1} % predicted was lower among residents living in poor air quality, which indicates cases of obstructive lung function, especially among severe cases. The severe category of FEV\textsubscript{1} % predicted also showed more respiratory morbidity cases compared to the other two categories of mild and moderate respiratory obstruction. Particulate matter (PM\textsubscript{2.5}, PM\textsubscript{1}) at a higher concentration can lead to poor ambient air quality in residential areas as evidenced from the present study. The present study proposes that higher PM concentrations (especially PM\textsubscript{1}) can lead to considerable variation in the prevalence of FEV\textsubscript{1} % <80% predicted among residents living in locations with a poor air quality index. Females are at a higher risk of obstructive lung function abnormalities compared to males. The confounding effect of age, sex, and smoking status on the risk of FEV\textsubscript{1} % predicted among residents was also demonstrated in the present study. Lung function (FEV\textsubscript{1} and peak expiratory flow rate (PEFR)) is influenced by age, sex, smoking habits, height, and weight, etc. Therefore, understanding the role of these physical characteristics on lung function is crucial. The mean ages of study subjects across locations were similar. Women showed a higher risk of obstruction-related lung function abnormality due to PM exposure than men. The study also found that the prevalence rate of obstruction cases in women increased with a corresponding increase in PM\textsubscript{1} and PM\textsubscript{25} from minimum to maximum concentration. Even though there was a higher risk of lower FEV\textsubscript{1} % predicted among females, only 19% were in the moderate category and 6% were in the severe category of respiratory problems. Mild category (50%) cases are mostly reversible and can be considered to be temporary.

Spirometric lung function parameters including FEV\textsubscript{1} % predicted are used as an early diagnostic tool and to monitor therapy effectiveness or the course of respiratory disease. Women showed a higher prevalence of FEV\textsubscript{1} % <80% predicted than their male counterparts. The gender-related prevalence of respiratory health problems in females may be attributed to biomass fuel exposure during cooking, which generates

<table>
<thead>
<tr>
<th>Age</th>
<th>N</th>
<th>FEV&lt;80% predicted</th>
<th>FEV&gt;80% predicted</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>18–40 yrs</td>
<td>558</td>
<td>397 (71.1)</td>
<td>161 (28.9)</td>
<td>1.31</td>
</tr>
<tr>
<td>&gt;40 yrs</td>
<td>296</td>
<td>226 (76.4)</td>
<td>70 (23.6)</td>
<td>(0.93 – 1.84)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sex</th>
<th>N</th>
<th>FEV&lt;80% predicted</th>
<th>FEV&gt;80% predicted</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>433</td>
<td>288 (66.5)</td>
<td>145 (33.5)</td>
<td>1.96</td>
</tr>
<tr>
<td>Female</td>
<td>421</td>
<td>335 (79.6)**</td>
<td>86 (20.4)</td>
<td>(1.42 – 2.71)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Smoking status</th>
<th>N</th>
<th>FEV&lt;80% predicted</th>
<th>FEV&gt;80% predicted</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non smokers</td>
<td>745</td>
<td>541 (72.6)</td>
<td>204 (27.4)</td>
<td>1.15</td>
</tr>
<tr>
<td>Smokers</td>
<td>109</td>
<td>82 (75.2)</td>
<td>27 (24.8)</td>
<td>(0.70 – 1.87)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Respiratory symptoms</th>
<th>N</th>
<th>FEV&lt;80% predicted</th>
<th>FEV&gt;80% predicted</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>688</td>
<td>497 (72.2)</td>
<td>191 (27.8)</td>
<td>1.21</td>
</tr>
<tr>
<td>Yes</td>
<td>166</td>
<td>126 (75.9)</td>
<td>40 (24.1)</td>
<td>(0.80 – 1.83)</td>
</tr>
</tbody>
</table>

Table 6 — FEV\textsubscript{1} % Predicted in Relation to Age, Sex, Smoking Status and Respiratory Symptoms

***p<0.001
higher PM in indoor air. Female subjects in all study locations in the present study cooked food using liquefied petroleum gas (LPG). LPG fuel is considered to be a better fuel compared to biomass fuels, as reported earlier, and all were non-smokers. Since the PM in indoor air was not measured in any household at any of the study locations, the role of indoor air pollutants in the reduction of lung function among women is unclear. However, an earlier study reported a reduction in lung function among women during cooking activities. Age and height are considered to be confounders for FEV₁. In this study, age and height were similar across locations, and hence the confounding effect on FEV₁ % predicted was nullified. Thus, the higher prevalence rate of obstructive lung functions among females can be considered to be an effect of PM, especially at fractions of 2.5 and 1 microns. Predicted values of lung functions should be reliable and representative of the reference cohort. In the present study, we used the representative reference values proposed for Indian male and female populations. This also makes our assumption of women being at higher risk due to PM pollution more reliable, since the reference equation used was for an Indian population. The decline in FEV₁ % predicted can also be attributed to the narrowing of the lower airways. In these conditions, the airway caliber or resistance and flow rates are proportional to the airway radius, especially in smaller airways.

The level of FEV₁ in relation to a predicted value is an indicator of the presence and severity of airflow impairment. The excessive rate of FEV₁ decline with respect to a predicted value is an indicator of ongoing respiratory health effects such as chronic obstructive pulmonary disease (COPD) progression. COPD is more commonly seen in people living in polluted areas, as well as those working in a dusty environment. Although COPD is multi-factorial by nature, it is generally caused by inhaled environmental and occupational exposures that may progress to chronic bronchitis, small airway disease or emphysema, and airway obstruction after prolonged and persistent injury to the airways.

A recent study by our group has shown that poor ambient air quality can lead to a reduction in lung function. Hence, the effect of PM₁₀ and PM₁₅ in ambient air can be proposed as one reason for the higher prevalence of FEV₁ < 80% predicted among residents. The risk of respiratory symptoms among study subjects was associated with higher concentrations of PM₁₀ and PM₁₅, although this was not significant in the present study. Higher rates of hospitalization or admission to emergency departments due to COPD were observed on days with elevated pollution in an earlier report. The increased prevalence of chronic bronchitis or emphysema, breathlessness, mucus hyper-secretion, and lower lung function parameters has been reported by the American National Health and Nutrition Examination Survey (NHANES), Adventist Health Air Pollution Study (AHSMOG), the Swiss Study on Air Pollution and Lung Disease in Adults (SAPALDIA), and earlier cross-sectional studies with respect to air pollution. In contrast, an examination of the association between long term exposures to traffic-related air pollution and lung function conducted by the European Study

<table>
<thead>
<tr>
<th>Change in PM₁₀ from min. value to different percentile values</th>
<th>Difference in Predicted FEV₁ %</th>
<th>% Fall in Predicted FEV₁ %</th>
<th>Change in PM₁₅ from Min. Value to Different Percentile Values</th>
<th>Difference in Predicted FEV₁ %</th>
<th>% Fall in Predicted FEV₁ %</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 (min)–56.5 (25th percentile)</td>
<td>1.46</td>
<td>1.97</td>
<td>50 (min)–100 (25th percentile )</td>
<td>1.90</td>
<td>2.73</td>
</tr>
<tr>
<td>12 (min)–87.5 (50th percentile)</td>
<td>2.48</td>
<td>3.35</td>
<td>50 (min)–159 (50th percentile )</td>
<td>4.14</td>
<td>5.96</td>
</tr>
<tr>
<td>12 (min)–120.5 (75th percentile)</td>
<td>3.56</td>
<td>4.81</td>
<td>50 (min)–194.5 (75th percentile )</td>
<td>5.49</td>
<td>7.90</td>
</tr>
<tr>
<td>12 (min)–179 (max)</td>
<td>5.48</td>
<td>7.40</td>
<td>50 (min)–323 (max)</td>
<td>10.37</td>
<td>14.93</td>
</tr>
</tbody>
</table>

Table 7 — Difference in Predicted FEV₁ % for a Proportional Increase in PM
of Cohorts for Air Pollution Effects (ESCAPE) showed that none of the lung function parameters were related to PM exposure.

The evolution of respiratory function involves several stages: a development stage that takes place in utero, a pulmonary growth stage that continues to young adulthood (20 years), a maturity stage between the ages of 20 and 30 years, and a stage of physiological decline, which is thought to begin after the age of 40 years. A multivariate analysis of FEV1 for different age groups in healthy Indian males also reported a significant decline in FEV1 after the age of 40–42 years. The age-related classification among residents in the present study also showed that the risk of FEV1 % <80% predicted among residents was higher at >40 years of age. This may also be considered as a physiological age-related decline. The SAPALDIA report found a 3.14% decrement in mean FVC for a 10 µg/m³ increase in ambient PM10. In the SAPALDIA study, it was observed that risks from air pollution, even though of a small magnitude, can affect lung function in the populations living there. The percentage of decline in mean FEV1 with PM10, and PM2.5, from the minimum to the maximum concentration was 4.5–16.8% and 2.5–13.9%, respectively. The percentage of decline in mean PEFR with increasing levels from minimum to maximum PM10 and PM2.5 was 5.8–22% and 4.9–26.4%, respectively.

To assess the impact of air pollution on lung function, epidemiological studies need to include large populations at different levels of exposure. Therefore, the present study was conducted in a relatively large sample size of 854 subjects (433 men and 421 women) with exposure to different levels of PM concentrations at different locations. The increasing trend for PM10 in metropolitan cities in India may be attributed to the increasing number of vehicles and natural dust. Urbanization in India involves a great deal of construction activity. NOIDA and Gurgaon in the NCR region are located at the boundary of New Delhi, a mega city and the capital of India. The cities surrounding the mega city, like NOIDA and Gurgaon, are in the development phase of urbanization. Therefore, large scale infrastructural development activities such as building and road construction activities are observed in these areas and they generate huge amounts of dust in the ambient air, resulting in poor air quality with regard to the concentrations of PM2.5 and PM10 in ambient air. PM emissions associated with motor vehicle movement in the study areas for infrastructure construction activities like road development can lead to respiratory ailments. Direct exhaust emissions from vehicles per se are limited in these areas. This can be attributed to the use of less polluted compressed natural gas as fuel in public motor transport vehicles at the study locations, as per the regulatory guidelines of the Indian government.

The Central Pollution Control Board in India monitored cities in the northern part of India for ambient air quality and reported poor air quality as per their classification of pollution levels. Our study location was also in the northern part of India. Hence, it is difficult to identify a control study location with good ambient air quality for particulate matter and control study subjects to compare with our study findings. Studies on the relationship between reduction in lung functions of residents living in areas with higher concentrations of PM in ambient air have been inconclusive. This is because most study populations have consisted of hospital admission cases. Very few studies, including our group study from India, have shown a relationship between PM concentration and its effect on lung functions in the same location.

**Study Strengths and Limitations**

The strength of the study is the large sample size of 854 subjects (433 males and 421 females). To date, this is the largest study sample size in an Indian population after recommended guidelines were introduced for PM10. Although this study has many strengths, it is not without limitations. The PiKo-1 spirometer used in the present study can measure PEF and FEV1. However, the device cannot be used to measure forced vital capacity or ratios used to categorize the patients with restriction-related lung function abnormalities. Further study is warranted to correlate the sources close to an individual participant’s residence (different fuel types, environment tobacco smoke and other indoor air sources) and around their work place (occupational exposures) with their respiratory health status. Personal dosimeter analysis was not used in this study due to feasibility and practical limitations. Even though the data set was five years old, large scale infrastructural development activities such as building and road construction activities observed in these areas continue to generate large amounts of dust in the ambient air in the study locations. Hence, we presume that the study data is still relevant. Due to the limited sample size in each study location, a statistical correlation analysis of lung functions with respiratory problems was not conducted for each study location. Household indoor air monitoring was also not conducted, which may be considered another limitation of the present study.

**Conclusions**

Higher concentrations of particulate
matter (PM$_{2.5}$, PM$_{10}$) have led to poor ambient air quality in the study locations, as evidenced from the present study. The present study shows that higher PM concentrations (especially PM$_{10}$) can lead to mild obstruction-related lung function abnormalities among residents, especially among women living in these locations. A reduction of PM emissions through strict interventions and regulations at the source or point of emission should be considered by policy makers and stake holders in these locations to reduce the burden of PM concentrations in ambient air. This can further reduce PM-related respiratory health problems. Similar studies should be conducted in other parts of the country to validate the observations of the present study. Exposure-response analysis for PM with respiratory health problems should also focus on children and the elderly population living in different geographical locations in India with poor air quality to understand the national scope of this problem.

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References


Research


34. Jindal SK. COPD: the unrecognized epidemic in India. J Assoc Physicians India [Internet]. 2012 Feb...


