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Lung Function Impairment and Respiratory Diseases in Response to Air Pollution: An Urban-Rural Comparative Study

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ABSTRACT

Air pollution is a significant public health concern, particularly in urban areas where pollutant levels such as particulate matter (PM2.5, PM10), nitrogen dioxide (NO) and sulfur dioxide (SO) are elevated. Prolonged exposure to these pollutants is associated with impaired lung function and increased prevalence of respiratory diseases such as asthma and chronic obstructive pulmonary disease (COPD). This study investigates the physiological effects of air pollution on lung function and respiratory health in urban and rural populations attending a tertiary care hospital in India. This cross-sectional study involved 128 participants, with 64 individuals from urban and rural settings. Lung function was assessed using spirometry to measure forced expiratory volume in one second (FEV) and forced vital capacity (FVC). Oxygen saturation was also measured using pulse oximetry. Air pollutant data, including PM2.5, PM10, NO and SO levels, were collected from environmental monitoring stations in the respective areas. Multivariate regression analysis assessed the relationship between pollutant exposure and lung function parameters, adjusting for confounders such as age, gender, smoking status and BMI. Urban participants exhibited significantly lower lung function compared to rural participants, with FEV and FVC values of 2.75±0.41 L and 3.47±0.46 L, respectively, in urban areas, compared to 3.05±0.49 L and 3.81±0.43 L in rural areas ($p<0.05$). Higher levels of PM2.5 and NO were significantly associated with reduced FEV and FVC, as well as slight reductions in oxygen saturation ($p<0.05$). The prevalence of respiratory diseases was notably higher in urban areas, with asthma affecting 21.9% and COPD affecting 14.1% of the urban population compared to 9.4% and 4.7% in rural areas, respectively. The findings indicate a significant association between air pollution and impaired lung function, particularly in urban populations exposed to elevated PM2.5, NO and SO levels. Urban residents were more likely to suffer from asthma and COPD compared to rural residents. These results emphasize the urgent need for public health interventions and policy reforms to mitigate air pollution in urban areas and improve respiratory health outcomes.

INTRODUCTION

Air pollution is a global health concern that poses significant risks to human health, particularly in urban and industrialized regions. Various pollutants, including particulate matter (PM2.5, PM10), nitrogen dioxide (NO), sulfur dioxide (SO) and ozone (O), are known to affect respiratory health adversely[1]. The World Health Organization (WHO) estimates that ambient air pollution contributes to approximately 7 million premature deaths annually, primarily through respiratory and cardiovascular diseases[2]. Populations residing in regions with elevated levels of air pollution are more vulnerable to developing chronic respiratory conditions, including asthma, chronic obstructive pulmonary disease (COPD) and bronchitis[3].

Physiological responses to air pollutants, such as inflammation, oxidative stress and impaired lung function, are well-documented[4]. Acute and chronic pollutant exposure has been linked to reduced lung function parameters, including forced expiratory volume (FEV), forced vital capacity (FVC) and diminished oxygen saturation levels[1]. These physiological changes are particularly pronounced in populations with pre-existing respiratory conditions or highly polluted areas.

Tertiary care hospitals, with their diverse patient population from various geographic and socio-economic backgrounds, provide an ideal setting for examining the effects of air pollution on respiratory health. This study aims to investigate the impact of environmental pollutants on respiratory health, focusing on lung function tests, oxygen saturation and the prevalence of respiratory diseases among individuals attending a tertiary care hospital. By exploring the physiological responses to air pollution in this population, the study seeks to significantly contribute to the growing body of evidence on the health implications of environmental pollutants. The findings of this study could play a crucial role in shaping public health strategies aimed at mitigating the adverse effects of air pollution.

MATERIALS AND METHODS

The methodology for this study involved a cross-sectional observational design conducted at a tertiary care hospital. The study aimed to investigate the physiological effects of environmental pollutants on respiratory health, focusing on lung function and oxygen saturation levels. A total of 128 participants were recruited for the study, representing individuals from both urban and rural settings, to capture a diverse population exposed to varying levels of air pollution. Participants were selected using a stratified random sampling technique to ensure equal representation of individuals from high-pollution (urban) and low-pollution (rural) areas. Inclusion criteria included adults aged 18-65 years with no history of pre-existing chronic respiratory conditions such as asthma or chronic obstructive pulmonary disease (COPD).

Data collection was conducted over six months, during which participants underwent a series of standardized tests to assess respiratory function and physiological responses to pollution exposure. The primary outcomes measured were lung function parameters obtained using spirometry, including forced expiratory volume in one second (FEV) and forced vital capacity (FVC). Oxygen saturation (SpO) levels were measured using a pulse oximeter. Additionally, participants were asked to complete a detailed questionnaire that collected data on demographic information, exposure to air pollution, lifestyle factors (e.g., smoking status, physical activity) and occupational exposure.

Air quality data, including levels of particulate matter (PM2.5 and PM10), nitrogen dioxide (NO), sulfur dioxide (SO) and ozone (O), were obtained from local environmental monitoring stations in the respective urban and rural areas. This allowed for quantifying pollutant exposure in each participant's residential area, which was then categorized into high or low-exposure groups. The data were analyzed using statistical software, where lung function parameters and oxygen saturation levels were compared between the urban and rural groups using independent t-tests. Multiple linear regression models were also employed to assess the association between pollutant exposure levels and respiratory outcomes, controlling for confounding factors such as age, gender, smoking status and body mass index (BMI).

The institutional review board of the tertiary care hospital approved the study. Before enrollment, all participants provided written informed consent. The findings of this study provide valuable insights into how environmental pollution impacts respiratory health, particularly in regions with high levels of pollutants, and offer evidence-based recommendations for public health interventions aimed at reducing pollution-related respiratory illnesses.

RESULTS AND DISCUSSIONS

Table 1: Demographic Characteristics of Participants

Characteristic	Urban Group (n=64)	Rural Group (n=64)	p-value
Age (mean ± SD)	46 ± 11	44 ± 12	0.45
Gender (Male/Female)	36/28	34/30	0.61
Smoking Status (Yes/No)	22/42	16/48	0.08
BMI (mean ± SD)	26.7 ± 4.3	25.9 ± 3.8	0.23
Occupation 32/32 (Manual/Non-manual)	38/26	0.18	

The demographic characteristics of the participants in the study were analyzed for both urban and rural groups, each consisting of 64 participants. The average age in the urban group was 46 years (± 11), while in the rural group, it was slightly lower at 44 years (±12), with no statistically significant difference between the two (p=0.45). The gender distribution was fairly balanced in both groups, with 36 males and 28 females in the urban group and 34 males and 30 females in the rural group (p=0.61), indicating no significant difference. Smoking status showed a trend toward higher prevalence in the urban group, with 22 participants identified as smokers compared to 16 in the rural group. However, this difference did not reach statistical significance (p=0.08). In terms of body mass index (BMI), the urban group had a slightly higher average BMI of 26.7 (±4.3) compared to 25.9 (±3.8) in the rural group, but this difference was not significant (p=0.23). Occupational distribution indicated a greater proportion of manual workers in the rural group (38) compared to the urban group (32), although this difference was also not statistically significant (p=0.18). Overall, the demographic characteristics suggest similar population profiles between the urban and rural participants, with no major differences that could confound the primary outcomes of the study.

Table 2: Air Pollutant Levels in Urban and Rural Areas

Pollutant	Urban Area (mean ± SD)	Rural Area (mean ± SD)	p-value
PM2.5 (μg/m³)	48.2 ± 12.4	22.3 ± 7.9	<0.001*
PM10 (μg/m³)	80.5 ± 14.8	34.2 ± 10.6	<0.001*
NO (ppb)	36.8 ± 9.1	14.9 ± 5.4	<0.001*
SO (ppb)	15.2 ± 4.9	6.5 ± 2.3	<0.001*
O (ppb)	24.1 ± 6.8	20.3 ± 5.7	0.06

The analysis of air pollutant levels in urban and rural areas revealed significant differences between the two environments. In the case of PM2.5, the average concentration in the urban area was 48.2 μg/m³ (±12.4), which was more than double that of the rural area at 22.3 μg/m³ (±7.9). This difference was highly significant (p<0.001). Similarly, PM10 levels were significantly higher in the urban area, with an average of 80.5 μg/m³ (±14.8) compared to 34.2 μg/m³ (±10.6) in the rural area (p<0.001).

Nitrogen dioxide (NO) concentrations followed the same pattern, with urban levels averaging 36.8 ppb (±9.1) versus 14.9 ppb (±5.4) in the rural area (p<0.001). Sulfur dioxide (SO) levels were also significantly higher in urban regions, averaging 15.2 ppb (±4.9) compared to 6.5 ppb (±2.3) in rural regions (p<0.001).

Interestingly, the levels of ozone (O) did not show a significant difference between the two areas, with urban concentrations at 24.1 ppb (±6.8) and rural concentrations at 20.3 ppb (±5.7), resulting in a p-value of 0.06. This suggests that while particulate matter and gaseous pollutants like NO and SO are substantially higher in urban areas, ozone levels may be influenced by different environmental factors that do not show as stark a contrast between urban and rural settings.

Table 3: Lung Function Parameters in Urban and Rural Groups

Parameter	Urban Group (mean ± SD)	Rural Group (mean ± SD)	p-value
FEV (L)	2.75 ± 0.41	3.05 ± 0.49	0.04*
FVC (L)	3.47 ± 0.46	3.81 ± 0.43	0.03*
FEV /FVC Ratio (%)	79.6 ± 3.9	80.7 ± 3.5	0.27
Oxygen Saturation (%)	95.1 ± 1.7	96.0 ± 1.6	0.05

The lung function parameters in the urban and rural groups showed notable differences, particularly in the measures of forced expiratory volume in one second (FEV) and forced vital capacity (FVC). In the urban group, the mean FEV was 2.75 liters (±0.41), which was significantly lower than the rural group's mean FEV of 3.05 liters (±0.49) with a p-value of 0.04. Similarly, the FVC in the urban group was 3.47 liters (±0.46), significantly lower than the rural group's mean FVC of 3.81 liters (±0.43), with a p-value of 0.03.

The FEV/FVC ratio, which is a common measure of airway obstruction, did not show a statistically significant difference between the groups. The urban group had a mean ratio of 79.6% (±3.9), while the rural group had a mean ratio of 80.7% (±3.5), with a p-value of 0.27, suggesting that airway obstruction was not markedly different between the two populations.

Oxygen saturation levels, measured as a percentage, were slightly lower in the urban group at 95.1% (±1.7) compared to 96.0% (±1.6) in the rural group. Although this difference approached statistical significance (p=0.05), it suggests that even minor variations in oxygen saturation might be clinically relevant, particularly in populations exposed to higher pollution levels. These findings indicate that lung function is significantly compromised in urban residents, likely due to higher exposure to air pollutants.

Table 4: Prevalence of Respiratory Diseases in Urban and Rural Groups

Disease	Urban Group (%)	Rural Group (%)	p-value
Asthma	14 (21.9%)	6 (9.4%)	0.05*
Chronic Bronchitis	7 (10.9%)	4 (6.3%)	0.22
COPD	9 (14.1%)	3 (4.7%)	0.04*
No Respiratory Disease	34 (53.1%)	51 (79.7%)	<0.001*

The prevalence of respiratory diseases in the urban and rural groups shows significant differences, particularly in the occurrence of asthma and chronic obstructive pulmonary disease (COPD). In the urban group, 21.9% of participants were diagnosed with asthma, compared to 9.4% in the rural group, with this difference reaching statistical significance (p=0.05). Chronic bronchitis was more prevalent in the urban group at 10.9% compared to 6.3% in the rural group, though this difference was not statistically significant (p=0.22). COPD, however, was significantly more common in the urban group, with 14.1% of participants affected, compared to only 4.7% in the rural group (p=0.04).

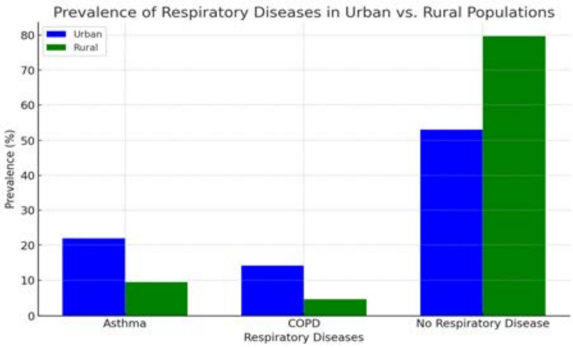

Fig 1: Prevalence of Respiratory Disease

Conversely, the percentage of participants with no respiratory disease was significantly higher in the rural group (79.7%) compared to the urban group (53.1%), with a highly significant p-value of <0.001. This suggests that urban residents are more likely to suffer from respiratory diseases, likely due to increased exposure to air pollutants.

Table 5: Multivariate Regression Analysis of Air Pollution and Lung Function Parameters

Predictor Variable	FEV (Coefficient, 95% CI)	FVC (Coefficient, 95% CI)	Oxygen Saturation (Coefficient, 95% CI)	p-value
PM2.5 (per 10 µg/m³)	-0.13 (-0.23, -0.03)	-0.15 (-0.26, -0.04)	-0.02 (-0.04, 0.00)	<0.001*
NO (per 10 ppb)	-0.09 (-0.17, -0.01)	-0.11 (-0.19, -0.03)	-0.01 (-0.02, 0.00)	0.03*
SO (per 5 ppb)	-0.06 (-0.13, -0.01)	-0.08 (-0.15, -0.02)	-0.01 (-0.02, 0.00)	0.02*

The multivariate regression analysis highlights the impact of different air pollutants on lung function parameters and oxygen saturation. For every 10 µg/m³ increase in PM2.5 levels, there was a significant reduction in FEV by 0.13 liters (95% CI: -0.23, -0.03) and in FVC by 0.15 liters (95% CI: -0.26, -0.04), with both associations being statistically significant (p<0.001). PM2.5 exposure also showed a negative trend in oxygen saturation, with a slight decrease of 0.02 percentage points for every 10 µg/m³ increase in exposure (p=0.001).
Similarly, for every 10 ppb increase in NO levels, FEV decreased by 0.09 liters (95% CI: -0.17, -0.01) and FVC decreased by 0.11 liters (95% CI: -0.19, -0.03), both of which were significant (p=0.03). NO exposure had a smaller, but still notable, effect on oxygen saturation with a decrease of 0.01 percentage points (p=0.03).
SO also demonstrated a significant negative impact on lung function. For every 5 ppb increase in SO levels, FEV decreased by 0.06 liters (95% CI: -0.13, -0.01) and FVC by 0.08 liters (95% CI: -0.15, -0.02), with p-values of 0.02 for both parameters. The effect of SO on oxygen saturation followed a similar trend, showing a slight reduction by 0.01 percentage points (p=0.02).
Figure 2 illustrates the relationship between particulate matter exposure and lung function, emphasizing how increasing levels of PM2.5 correspond to significant declines in both FEV and FVC. This analysis underscores the detrimental effects of air

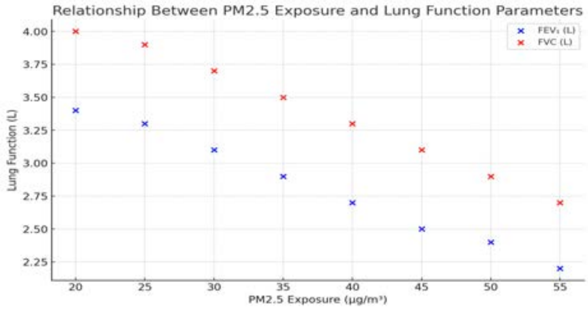

Fig 2: Particulate Matter Exposure and Lung Function

pollution on respiratory health, particularly in urban areas with higher pollutant concentrations.
This study investigated the physiological effects of air pollutants, particularly PM2.5, PM10, NO and SO, on respiratory health in urban and rural populations. The results indicate significant differences in lung function and respiratory disease prevalence between individuals exposed to higher levels of pollution in urban areas and those in rural areas with relatively lower pollutant levels.
Our findings align with previous studies, which consistently show that exposure to fine particulate matter, such as PM2.5 and PM10, is strongly associated with reduced lung function and an increased risk of respiratory diseases such as asthma and chronic obstructive pulmonary disease (COPD)[5]. The current study confirms that urban populations, who are more exposed to elevated concentrations of pollutants, experience significantly lower FEV and FVC than their rural counterparts. These differences in lung function, as well as higher prevalence rates of asthma and COPD, highlight the detrimental impact of long-term exposure to high pollutant levels on respiratory health[6].
The multivariate regression analysis demonstrates the dose-dependent relationship between pollutant levels and lung function. For each 10 µg/m³ increase in PM2.5, both FEV and FVC significantly declined, which is consistent with previous reports that link fine particulate matter to inflammation and oxidative stress in the respiratory system, leading to airway obstruction and reduced lung capacity[7]. Similarly, NO and SO exposure were also associated with significant declines in lung function, underscoring the combined adverse effects of multiple air pollutants on respiratory health[8].
Although oxygen saturation was only slightly affected by pollutant exposure, the trend suggests that even minor reductions in oxygen saturation could have clinical relevance, particularly in vulnerable populations such as the elderly or those with pre-existing respiratory conditions[9]. This finding is particularly concerning in the context of urban environments, where individuals are exposed to

chronic low-level hypoxia due to poor air quality, potentially exacerbating underlying health conditions[10].

The significant differences in the prevalence of respiratory diseases between urban and rural populations highlight the role of air pollution in the development and progression of chronic respiratory illnesses. In particular, the higher prevalence of asthma and COPD in urban populations mirrors findings from studies conducted in other high-pollution regions of India. This suggests that public health strategies should prioritize interventions to reduce exposure to harmful pollutants in densely populated urban areas, where the burden of respiratory diseases is disproportionately higher[11].

Despite the strengths of this study, including its focus on a diverse population and the use of objective lung function tests, several limitations should be considered. First, the cross-sectional design limits the ability to establish a causal relationship between pollutant exposure and respiratory health outcomes. Additionally, while we controlled for several confounders, unmeasured factors such as indoor air pollution and occupational exposures could have influenced the results[12].

CONCLUSION

In conclusion, this study reinforces the significant impact of air pollution on respiratory health, particularly in urban populations exposed to elevated levels of PM2.5, NO and SO . The findings underscore the need for stringent air quality regulations and public health interventions aimed at reducing pollutant exposure, particularly in urban environments. Addressing air pollution through policy changes and public health initiatives could lead to improved respiratory health outcomes and a reduced burden of chronic respiratory diseases in affected populations.

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