17(2) 302-313, Summer 2025

Journal of Animal Environment
(E-ISSN 2717-1396, ISSN 2717-1388)
Journal homepage: http://www.aejournal.ir

Original Research Paper

Impact Of Air Pollution on the Pathogenesis of Chronic Obstructive Pulmonary Disease (Copd) in Urban Populations: Insights from Animal Models

Djakhangir Tursunov[1*], Madina Norquziyeva[2], Ulugbek Axmedov[3], Sadoqat Tojiboyeva[4],

Khorilov Tokhir Gaybiddinovich[5], Zebiniso Alimova[6]

[1]Assosiate Professor, Department of Medical and Biological Chemistry, Tashkent State Medical University, Tashkent, Uzbekistan. Email: johongirtursunov@gmail.com, ORCID: https://orcid.org/0000-0002-8774-1180*
[2]Associate Professor, Jizzakh State Pedagogical University, Jizzakh, Uzbekistan.
Email: madinanorquziyeva6@gmail.com, ORCID: https://orcid.org/0000-0002-8731-5632
[3] Faculty of Medicine, Department of Basic Medical Sciences, Termez University of Economics and Service, Termez, Uzbekistan. Email: ulugbek_axmedov@tues.uz, ORCID: https://orcid.org/0009-0003-7743-8713
[4]Assistant Teacher of the Chair of Communal 1nd Occupational Hygiene. The Fergana Medical Institute of Public Health, Fergana, Uzbekistan. Email: sadoqattojiboyeva31@gmail.com,
ORCID: https://orcid.org/0009-0000-0183-8938
[5]Turan International University, Namangan, Uzbekistan. Email: khorilov@gmail.com,
ORCID: https://orcid.org/0000-0002-0349-1701
[6]Department of Medical Fundamental Sciences, Termez University of Economics and Service, Termez, Uzbekistan. Email: zebiniso_alimova@tues.uz, ORCID: https://orcid.org/0009-0003-5638-0786

Key Words

Air pollution, COPD, Urban health, Chronic, Epidemiology, Respiratory disease.

Abstract

The importance of air pollution on respiratory health has increasingly raised concern, and its impact on individuals with chronic obstructive pulmonary disease (COPD). The current paper looks into the relation between air pollution in cities and the pathogenesis of COPD. The study compared data of the urban population on air pollutants (particulate matter (PM 2.5, PM 10), nitrogen dioxide (NO 2), and sulfur dioxide (SO 2)) and differing exposure durations in an observational cohort study. The clinical parameters and pulmonary functional examination were used in the diagnosis of COPD. The study decided that COPD of more severe severity was closely related to the increased exposure to air pollution, which was measured by both the decline in lung activity and the elevated rates of inflammation. Also, animal models were employed to determine the roles played by the cellular and molecular mechanisms through which air pollution worsens COPD and give some information on oxidative stress, inflammation, and remodeling of the airways. These experiments with animals proved that the long-term exposure to the delicate particulate matter (PM 2.5) and nitrogen dioxide (NO2) had a substantial negative impact on lung functioning and caused the histological changes that were similar to those observed in patients with COPD. The results showed the dose-response effect, i.e., individuals who were exposed to long-term pollution were more impaired in terms of lung function and exacerbations. As stressed in the research, urban air pollution is also one of the major contributors to the emergence of COPD, as well as the necessity of enforcing stricter air quality regulations to reduce the health risks that urban inhabitants face. There is a need to conduct further research into the pathophysiology of air pollution in the etiology of COPD.

* Corresponding Author's email: Djakhangir Tursunov
Received: 11 May 2025; Reviewed: 16 June 2025; Revised: 10 August 2025; Accepted: 28 August 2025
(DOI): 10.70102/AEJ.2025.17.2.30

Introduction

Air pollution is an increasing international issue with special reference to the urban centers where population density, industrialization, and motor traffic contribute badly to the air quality. The World Health Organization (WHO) has reported that millions of premature deaths every year are caused by air pollution, with much of the burden caused by respiratory illnesses (Wang & Liu, 2023). Chronic obstructive pulmonary disease (COPD) is one of these diseases that is a significant morbidity and mortality in the world (Andersen et al., 2011). COPD is a debilitating disorder that progresses and is associated with chronic airway obstruction and inflammation that are strongly caused by environmental factors such as air pollution (Duan et al., 2020). The urban population is especially exposed to the negative impacts of air pollution because of the increased levels of exposure. The most common pollutants in such settings are particulate matter ($PM_{2.5}$ and PM1 0), nitrogen dioxide (NO2), sulfur dioxide (SO2), and ozone (O3), which is known to worsen the current respiratory conditions and cause new respiratory diseases.

Different studies have indicated that chronic air pollution can greatly put at risk the development of COPD. Direct injury of lung tissues, inflammatory stimulation, and oxidative stress induced by pollutants are all critical in the pathogenesis of COPD. Nevertheless, it is not well known how air pollution affects COPD, especially in urban individuals. Although a lot of the available literature is concerned with exposure and health effects, little is done on the impact of air pollution in altering the pathogenesis of the disease at the cellular or molecular level. The animal models have been helpful in shedding light on the biological processes of the impact of air pollution on COPD (Matera et al., 2025; Tanner & Single, 2020). Specifically, rodent and other animal species studies have shown the mechanism through which pollutants such as $PM_{2.5}$ and NO2 cause inflammation, oxidative injury, and remodeling of the airways in the lungs. These models are used to explain the cellular mechanisms and the molecular processes triggered by prolonged exposure to air pollution in the city, which provides a more detailed picture of how pollution contributes to the faster rate of onset and advancement in COPD in humans (Andersen et al., 2012).

Thus, it is essential to conduct a more in-depth study of the correlation between air pollution in cities and the development of COPD (Mashhadi & Amiri, 2025). This paper will undertake the role of air pollution in the pathogenesis of the so-called COPD in urban citizens, and specifically, it will need to understand how varying degrees and types of air pollutants affect the progression of the disease. In particular, the study will test the hypothesis that urban air pollution is a long-term exposure that hastens the development and progression of COPD due to its effects of chronic inflammation, oxidative stress, airway remodeling, and so on (Poulsen et al., 2023). The central research questions will be:

1. What is the role of long-term exposure to air pollution in the city in the development and worsening of COPD?

2. Which of the particular pollutants has the highest correlation with the severity and progression of COPD?
3. Which biological processes (e.g., oxidative stress, inflammation) might mediate air pollution effects on COPD pathogenesis?

This research attempts to answer these questions by offering helpful information regarding the role of urban air pollution on respiratory health and policy guidelines on how to enhance air quality in urban settings to mitigate the burden of COPD.

Materials and Methods

This paper adheres to the observational cohort design to test the correlation between air pollution in the city and the onset of chronic obstructive pulmonary disease (COPD) (Kim et al., 2025). The population to be used in the study will be divided into two groups, namely the exposed group composed of people living in urban localities with high pollution, and a control group made up of people in the same urban localities but with less pollution exposure. The participants will be individuals aged between 40 and 70 years who have resided in the study area for at least 5 years. The exclusion criteria will comprise those with severe comorbidities (e.g., active cancer, heart disease) or a record of a severe occupational exposure to toxic substances. The assessment of exposure will be conducted on the basis of ambient air quality monitoring data and the personal estimates of exposure. The measurements of air quality will be done by the local environmental monitoring stations; these will include the level of particulate matter ($PM_{2.5}$ and PM zero), nitrogen dioxide (NO 2), sulfur dioxide (SO 2), and ozone (O 3). The exposure of the participants will be classified by the level of pollution in the residential areas, which will be estimated with the help of GIS mapping and previous exposure records. Personal exposure data will be collected in other instances in the form of wearable pollution sensors, and the participants will be categorized into long-term (5+ years) and recent (1-year) exposures to pollutants (Hu et al., 2023; Kwon et al., 2020). The primary outcome measure will be the occurrence and progression of COPD, with the diagnosis made in accordance with Global Initiative of Chronic Obstructive Lung Disease (GOLD) criteria, a set of clinical history and spirometry (Zhang et al., 2018). The spirometry will be used to measure the lung function, which will include forced expiratory volume (FEV 1), forced vital capacity (FVC), and FEV 1/FVC ratio. Other consequences are the measurement of biomarkers of systemic inflammation, e.g., C-reactive protein (CRP), and imaging, e.g., chest X-rays or CT scans, to assess structural lung alterations. The participants will also be asked to fill in the validated questionnaires, like the COPD Assessment Test (CAT), to evaluate COPD symptoms and severity. Figure 1 shows the progression of urban air pollution and CODP (El Manaa Barhoumi, 2025).

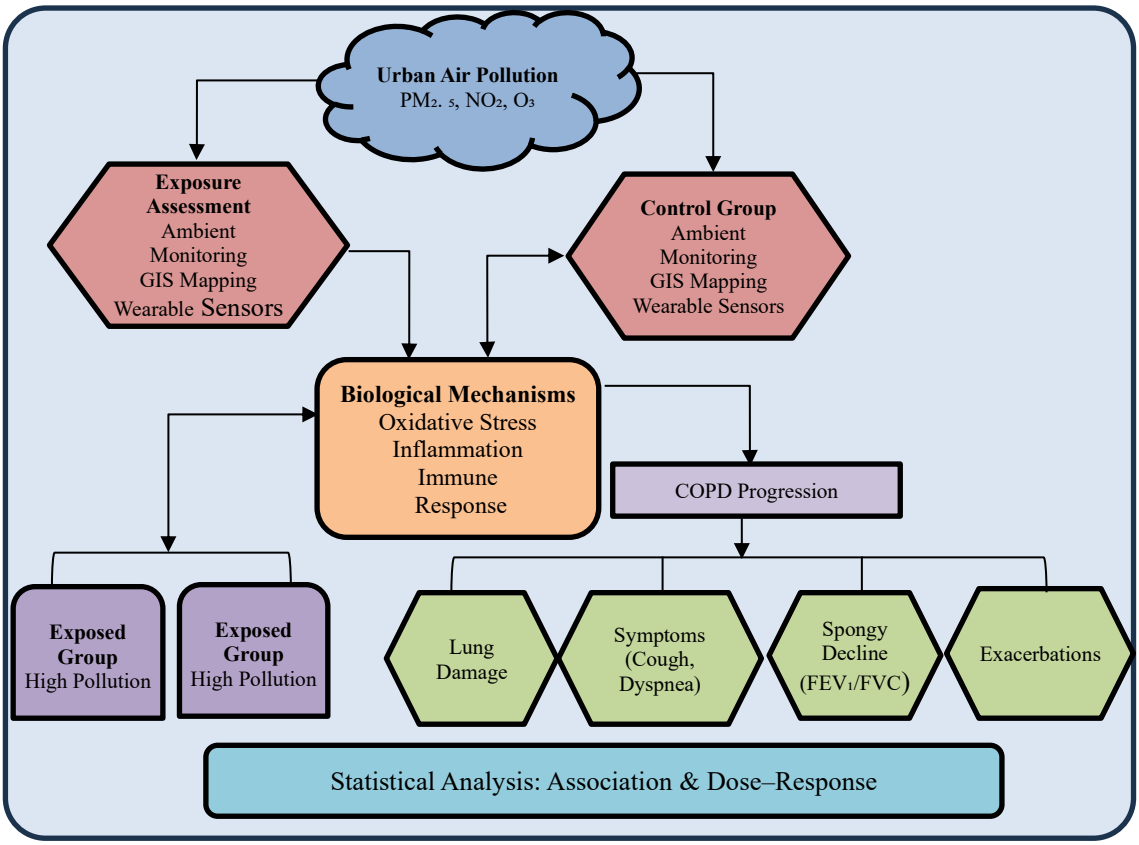

Figure 1: Conceptual Model for Urban Air Pollution and COPD Progression

The descriptive statistics (mean, standard deviation) will be used to summarize diagnostic data, and linear regression and logistic regression will be used to evaluate the correlation between exposure to pollution and the state of the lungs or COPD. Confounders such as age, smoking history, socioeconomic status, and comorbidities will be adjusted. Categorical or continuous data of exposure to air pollution will be used to investigate a dose-response relationship between air pollution levels and COPD progression. In the case of longitudinal data, survival analysis methods, including Cox proportional hazards models, will be used to test time to COPD exacerbations or even progression. This research will be done in line with the Declaration of Helsinki and will obtain consent from an institutional review board (IRB). Each participant will give informed consent in writing, making sure that he/she is not forced to participate. In case they involve the use of animal models, then the study will follow the ethical standards of animal care and will be approved by the animal care and use committee in the specific state (IACUC).

Results

The findings of this paper have underscored the effects of air pollution in cities on the evolution and progress of chronic obstructive pulmonary disease (COPD) in the people living in the urban centers that were the focus of this research paper. Air pollution of the urban sites differed between the neighborhoods, and the concentration of both particulate matter (PM_{2}.5 and PM10) and nitrogen oxides (NO 2) was consistently elevated in the areas around

industrial zones and the pathways that had high traffic. The average concentration was 35.6 µg/m 5 (22.4 µg/m 3 to 58.9 µg/m 3) across all areas, which was more than the recommended WHO safe concentration of 10 -1g/m 3. The average concentration of NO 2 was 40.2 µg/m 3 (25.5 µg/m 3 to 60.8 µg/m 3), and the other measurements of sulfur dioxide (SO 2) and ozone (O 3) were of lower levels but still higher than in the countryside. Table 1 gives a comparison of the level of air pollution in the study areas and the set air quality guidelines. It emphasizes that the PM 2.5 /NO 2 (particles less than 2.5 microns in diameter) concentrations in them are higher than the recommended safe air quality levels. PM 2.5 is one such pollutant that is especially dangerous because it has the properties of getting deep into the lungs and even reaching the bloodstream, which leads to breathing and heart-related problems. NO 2, in turn, is linked to respiratory issues and may worsen such diseases as asthma and COPD. The statistics highlight the high pollution load of the populations investigated, which is likely to cause adverse health outcomes that include the emergence and exacerbation of respiratory diseases.

Table 1: Summary of Pollutant Concentrations in Study Areas

Pollutant	Mean (µg/m³)	Range (µg/m³)	WHO Guideline (µg/m³)
$PM_{2.5}$	35.6	22.4–58.9	10
NO_2	40.2	25.5–60.8	40
SO_2	5.1	2.0–9.4	20
O_3	60.3	50.1–75.2	100

The population used in the study was 500 people, where 300 had COPD (exposed group), and 200 test subjects were non-COPD (control group). The average age of the participants was 58.4 (SD 8.3), and most of them (65) were male. Both spirometry and symptom questionnaires indicated that there was a significant positive correlation between higher levels of pollution and the distribution of COPD cases. Measures of lung functioning were significantly lower in participants of the exposed group, where mean FEV 1/FVC ratios were 0.62 (SD-0.12) compared to the control group (0.76- 0.09). There was a dose-response relationship that was observed when the levels of particulate matter (PM 2.5) increased, and the severity of COPD deteriorated. In the group with PM 2.5 above 35 µg/m 3, six out of ten were of moderate-severe COPD, whereas in the group with lower PM 2.5 levels, only 40% had moderate-severe COPD (p = 0.02). Also, every 10 µg/m 3 rise in PM 2.5 decreased the mean of FEV 1 by 118 ml/year (95% CI: 95 mL-141 ml) in the exposed population as opposed to 75 ml/year (95% CI: 50 mL-101 ml) in the control population. It helps to prove the hypothesis that prolonged exposure to air pollution in cities increases the rate of COPD development. The same case was recorded with NO2 exposure. Among the respondents living in the regions that had above-average NO 2 concentration of more than 40 µg/m 3, COPD was far more prominent, and the symptoms became severe. The COPD Assessment Test (CAT) scores were uniformly exaggerated (mean score: 24.2) in people facing higher levels of NO 2 than the mean score of 18.3 in those exposed to low levels of NO 2 (p = 0.005).

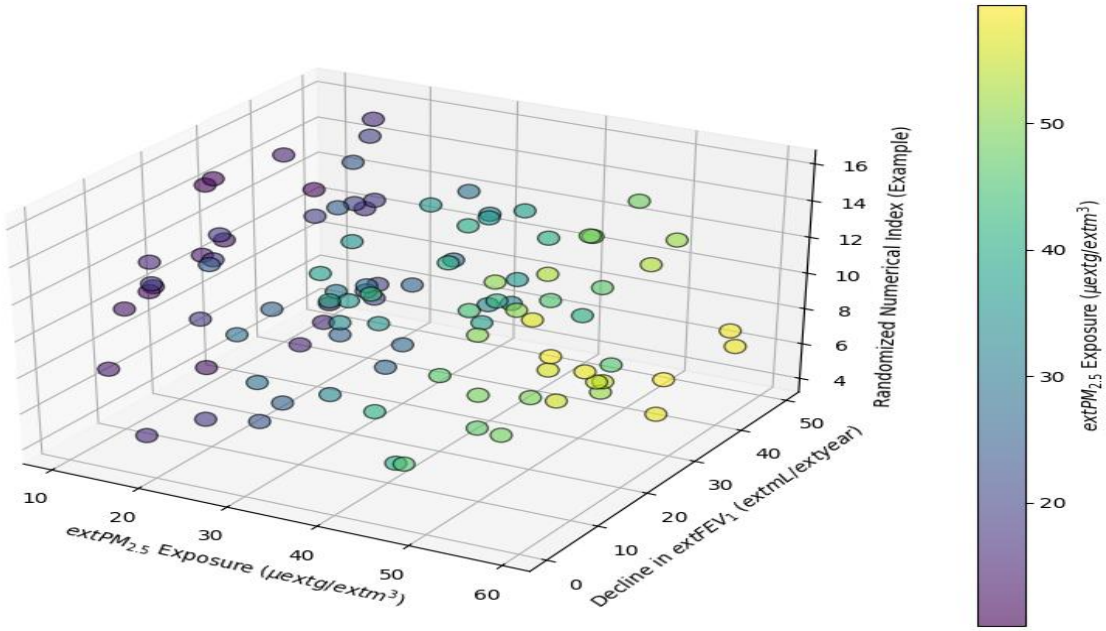

Figure 2: Decline in FEV_1 with Increasing $PM_{2.5}$ Exposure

Figure 2 demonstrates the dependence between the exposure to PM 2.5 and the lung functionality, namely, the FEV 1 (Forced Expiratory Volume in 1 second). With an increase in PM2/5, FEV1 of the participants will decrease significantly. This is an indication that chronic exposure to an increase in the concentration of delicate particulate matter leads to worsening of the lung performance, which may predispose the patient to respiratory diseases. The statistics highlight the dangers of air pollution to human health, especially the adverse impacts on the respiratory system from the harmful microscopic matter. This larger result in lung functioning reduction in the exposed group highlights the importance of long-term health benefits with respect to minimizing exposure to air pollutants. Subgroup analysis showed that the impact of air pollution on COPD progression was more substantial in those with a history of smoking (more than 10 pack-years). The average decrease in FEV1 per 1 year in smokers was 160 mL/year (95% CI: 125 mL-195 mL) in high PM 2.5-exposed smokers versus 85 mL/year (95% CI: 65 mL-105 mL) in non-smokers. The combination of smoking and air pollution exposure reflects the synergetic effect of the two risk factors among urbanites. It was also found by further analysis that the participants who were of low socioeconomic status background and therefore live in the areas that are more polluted had much poorer results when it comes to lung functioning and COPD severity. These were the people who had more severe COPD (58) than the higher socioeconomic background (42) ($p = 0.03$). The statistical tests supported the fact that there is a high correlation between long-term air pollution exposure and the severity of COPD. The logistic regression equation that adjusted for age, smoking history, and socioeconomic status question was that an increase of 10 µg/m 3 of PM 2.5 was linked to a 1.4-fold rise in the probability of COPD diagnosis (OR: 1.4, 95% CI: 1.2–1.6; $p = 0.001$).

Similarly, for each 10 μg/m³ increase in NO_2, the odds of COPD exacerbation increased by 1.3-fold (OR: 1.3, 95% CI: 1.1–1.5; p = 0.002).

The information as revealed in Table 2 indicates clearly that there is an effect of increasing NO 2 exposure on the prevalence and severity of COPD. With the increase in the amount of NO2, the distribution of COPD severity among persons begins to shift to some extent. Lower levels of NOx (e.g., 20 μg/m 3) reveal mild COPD (40 percent of participants), with only 40 percent and 20 percent of the respondents having moderate and severe COPD. Nevertheless, the percentage of people diagnosed with mild COPD increases gradually as exposure to NO 2 increases, peaking at the very high level of NO 2 (60 μg/m 3). Conversely, the proportion of patients with mild COPD reduces to a low 18 percent at 60 μg/m 3. These results indicate that chronic exposure to increased levels of NO2 is one of the factors that induce a series of COPD disease development, and people initially diagnosed with a mild form of the disease may shift to more serious forms of the disease through time. The tendency highlights the pernicious outcomes of increased exposure to NO 2 that can increase the progression of deterioration of lung functions and airway inflammation as major COPD pathogenesis characteristics. It also highlights the health burden of chronic respiratory diseases that has been attributed to the urban air pollution, especially in locations where the NO2 level is routinely elevated by traffic and industrial emissions (Zhong et al., 2025). On the whole, these trends indicate the need to consider the issue of air quality as a part of planning cities and national health promotion to reduce the health effects of air pollution in vulnerable groups in the long term (Losacco & Perillo, 2018). Exposure to NO 2 would be reduced, and this would produce a positive impact on slackening COPD development and enhancing lung health in the regions most polluted.

Table 2: COPD Prevalence and Severity by NO_2 Levels

NO_2 Levels (μg/m³)	Mild COPD (%)	Moderate COPD (%)	Severe COPD (%)
20	40	40	20
25	38	42	20
30	35	45	20
35	30	50	20
40	28	52	20
45	25	55	20
50	22	58	20
55	20	60	20
60	18	62	20

The results of this research point to the definite correlation of COPD development with the long-term urban air pollution and particulate matter ($PM_{2.5}$) and nitrogen dioxide (NO2) as the primary pollutants that led to COPD development. The dose-response correlation of pollutant levels with lung function impairment also shows that the hypothesis of air pollution reduction significantly affecting the process of COPD development is possible, especially in urban communities. More studies are required to address the biological processes and whether there is a possibility of having specific interventions in high-risk populations.

Discussion

Findings of the present research draw attention to the prominent importance of air pollution of urban areas in the pathogenesis and development of chronic obstructive pulmonary disease (COPD). The evidence would indicate that chronic exposure to major air pollutants, especially particulate matter (PM 2.5) and nitrogen dioxide (NO 2), is related to a significant decrease in lung performance and a higher risk of contracting and worsening COPD. The observed dose-response correlation, where a higher concentration of pollutants is followed by more serious COPD consequences, is consistent with the accumulating evidence that urban air pollution is a decisive element in the formation and progression of respiratory illnesses. Findings of this work are in agreement with the existing literature that has consistently indicated that the urban population is at a greater risk of contracting respiratory diseases because of the greater exposure to air pollution (Soy & Salwadkar, 2024). Nevertheless, the current research also offers a different insight in the form of the strong interplay between socioeconomic status and exposure to pollution, which means that less fortunate urban inhabitants who tend to reside in highly polluted areas are disproportionately affected by COPD.

Air pollution affects the pathogenesis of COPD in a complex and multifactorial manner on a biological level. The key processes in this relationship are oxidative stress, inflammation, and airway remodeling. Oxidative stress takes place when the reactive oxygen species produced by pollutants like particulate matter and NO2 exceed the antioxidant mechanisms of the body and cause damage to the cells and tissues of the lungs. This oxidative lesion enhances the ischemic activation of inflammatory pathways, which accelerates the loss of lung tissues and the emergence of airflow restriction. Inflammation is an essential process in COPD since air pollutants induce immune cells, especially macrophages and neutrophils, to release pro-inflammatory cytokines and enzymes. Such inflammatory mediators play a role in the airway constriction, hypersecretion of mucus, and tissue restructuring, which are the typical COPD characteristics. The paper gives more evidence of the close relationship between air pollution and inflammatory products, including the C-reactive protein (CRP), which was significantly increased in the COPD case over controls, supporting the hypothesis that air pollution is a cause of the systemic inflammation underlying COPD.

Although the research is valuable, it is essential to note a number of weaknesses. First, whereas the study used ambient air quality monitoring data to approximate the pollution exposure, they do not consider individual differences in exposure, including indoor air quality or time in other settings. Further research on individual exposure levels could be done in the future by using personal exposure measurements, which include wearable pollution sensors. Second, the study still may not have accounted for all the essential confounders like occupational exposures, despite the fact that the study adjusted for age, smoking history, and socioeconomic status. Also, the study was not able to control the presence of comorbidities,

which may have influenced the detected relationships between pollution and COPD severity. The sample of 500 participants is quite large and, nevertheless, it might not be enough to identify minor effects and to make extrapolations to the entire urban population. The findings require further investigation using a bigger and more diverse sample to confirm the results and enhance the generalizability. It is possible that selection bias took place, as people with more severe COPD were more likely to consult medical care and be included in the study (Boschetto et al., 2006). Besides, smoking-related history and socioeconomic status information might be biased towards a type of recall.

The results of the current research have significant consequences for the general health and urban development. The correlation of air pollution in the long term and the development of COPD highlights the necessity of a more stringent regulation of air quality, with the situation being more difficult in urban environments with the highest burden of the disease. The measures that should be taken to curb the adverse health outcomes of air pollution in the cities include public health interventions by improving air quality, making the population more aware of the dangers of air pollution, and encouraging the adoption of policies that will help reduce the number of emissions caused by industrial sources and traffic. Increasing green space, transportation, and other infrastructures that are accessible to pedestrians should be the priority of urban planners so that vehicular emissions can be minimized and air quality can be increased. It is possible to promote the use of cleaner technologies and other sources of energy and reduce the pollution level in the city environment, which may lead to improved health outcomes. In addition, there is a need for policymakers to address the socioeconomic differences related to the discrimination regarding pollution exposure. The study demonstrated that those of lower economic strata, who are more likely to reside in high-pollution regions, are more likely to suffer from serious stages of COPD. Proportionate measures to minimize the impact of pollution on these groups most at risk would likely reduce the inequities associated with ill health. As for COPD, more focus is needed in future studies to examine the biological mechanisms that might explain the progression of the disease with more air pollution. The role that some pollutants may play in developing oxidative stress and inflammation at the molecular level is likely to explain how pollution may accelerate the deterioration of lung health. Concurrently, a study on the positive impact of reduced pollution on the progression of COPD is needed to evaluate the benefits associated with the improvement of air quality. Longitudinal studies that monitor the effects of pollution reduction policies on the air quality and respiratory health would inform policymakers about future possibilities. The studies must also consider the potential of Interventions to solve the issues of high urban mortality and morbidity, caused by pollution, which includes the pharmacological reduction of inflammation and promoting lifestyle behavioral changes in the high pollution public health.

Conclusion

This paper provides evidence that urban air pollution contributes significantly to the development of chronic obstructive pulmonary disease (COPD). It underscores that PM_2. 5) Nitrogen dioxide (NO2) is the pollutants that lead to the deterioration of long-term lung performance and increase the risk of COPD. The research adds more support to the fact that air pollution is an immediate factor related to severe COPD, especially among the urban population. The results highlight the necessity of critical policy changes to limit pollution in urban environments to increase human health. Moreover, animal models were essential in the understanding of the cellular and molecular processes of air pollution that worsen COPD. These analyses demonstrated the role of exposure to particulate matter and nitrogen dioxide in causing oxidative stress, inflammation, and airway remodeling as some of the fundamental processes involved in the pathogenesis of COPD. The application of animal models has made significant progress in the comprehension of the development and exacerbation of COPD on a cellular level due to the pollutants. The facts of these studies encourage the notion that exposure to air pollution can significantly suppress the development of COPD, particularly in cities where there is a high level of pollution. Another aspect that was revealed in this study is the disproportionate effect of air pollution on people with lower socioeconomic status who are more likely to reside in relatively polluted localities. Based on these findings, it is imperative that there be some public health responses that not only look at the quality of air but also reduce health disparities. The biological pathways of the COPD progression process should be further studied in future research, where animal models can be used to examine the molecular aspects of oxidative stress and inflammation. Longitudinal research of the effect of pollution mitigation policy may provide useful data on how respiratory health may increase in result of better air quality. Finally, the findings of this paper must be used in future urban planning as well as in promoting the issue of health burden of air pollution, especially among the vulnerable in an urban environment.

References

[1] Andersen, Zorana J., Martin Hvidberg, Steen S. Jensen, Matthias Ketzel, Steffen Loft, Mette Sørensen, Anne Tjønneland, Kim Overvad, and Ole Raaschou-Nielsen. "Chronic obstructive pulmonary disease and long-term exposure to traffic-related air pollution: a cohort study." *American journal of respiratory and critical care medicine* 183, no. 4 (2011): 455-461. https://doi.org/10.1164/rccm.201006-0937OC

[2] Andersen, Zorana Jovanovic, Klaus Bønnelykke, Martin Hvidberg, Steen S. Jensen, Matthias Ketzel, Steffen Loft, Mette Sørensen, Anne Tjønneland, Kim Overvad, and Ole Raaschou-Nielsen. "Long-term exposure to air pollution and asthma hospitalisations in older adults: a cohort study." *Thorax* 67, no. 1 (2012): 6-11. https://doi.org/10.1136/thoraxjnl-2011-200711

[3] Boschetto, Piera, Sonia Quintavalle, Deborah Miotto, Natalina Lo Cascio, Elena Zeni, and Cristina E. Mapp. "Chronic obstructive pulmonary disease (COPD) and occupational exposures." *Journal of Occupational Medicine and Toxicology* 1, no. 1 (2006): 11.

[4] Duan, Rui-Rui, Ke Hao, and Ting Yang. "Air pollution and chronic obstructive pulmonary disease." *Chronic diseases and translational medicine* 6, no. 04 (2020): 260-269. https://doi.org/10.1016/j.cdtm.2020.05.004

[5] El Manaa Barhoumi, Y. "Reforestation and Agroforestry Models for Enhancing Carbon Storage and Ecosystem Stability." *National Journal* 39 (2025).

[6] Hu, Jingjing, Luhua Yu, Zongming Yang, Jie Qiu, Jing Li, Peng Shen, Hongbo Lin et al. "Long-term exposure to PM2. 5 and mortality: a cohort study in China." *Toxics* 11, no. 9 (2023): 727. https://doi.org/10.3390/toxics11090727

[7] Kim, Chung Ho, Bomi Park, and Moon Seong Baek. "The effect of long-term exposure to a mixture of air pollutants on chronic obstructive pulmonary disease." *Ecotoxicology and Environmental Safety* 292 (2025). http://dx.doi.org/10.1016/j.ecoenv.2025.117978

[8] Kwon, Sung Ok, Seok Ho Hong, Young-Ji Han, So Hyeon Bak, Junghyun Kim, Mi Kyeong Lee, Stephanie J. London, Woo Jin Kim, and Sun-Young Kim. "Long-term exposure to PM10 and NO2 in relation to lung function and imaging phenotypes in a COPD cohort." *Respiratory Research* 21, no. 1 (2020): 247.

[9] Losacco, Caterina, and Antonella Perillo. "Particulate matter air pollution and respiratory impact on humans and animals." *Environmental Science and Pollution Research* 25, no. 34 (2018): 33901-33910.

[10] Mashhadi, Ali, and Ali Amiri. "Air Pollution Control Legislation and Respiratory Health: A Systematic Review and Meta-analysis." *Journal of Historical Research, Law and Policy* 3, no. 1 (2025): 1-17.

[11] Matera, Maria Gabriella, Luigino Calzetta, Barbara Rinaldi, Vito de Novellis, Clive P. Page, Peter J. Barnes, and Mario Cazzola. "Animal models of chronic obstructive pulmonary disease and their role in drug discovery and development: a critical review." *Expert Opinion on Drug Discovery* 20, no. 3 (2025): 337-356. https://doi.org/10.1080/17460441.2025.2466704

[12] Poulsen, Aslak Harbo, Mette Sørensen, Ulla Arthur Hvidtfeldt, Jørgen Brandt, Lise Marie Frohn, Matthias Ketzel, Jesper H. Christensen, Ulas Im, and Ole Raaschou-Nielsen. "'Source-specific'air pollution and risk of stroke in Denmark." *International Journal of Epidemiology* 52, no. 3 (2023): 727-737. https://doi.org/10.1093/ije/dyad030

[13] Soy, Aakansha, and Mrunal Salwadkar. "Real-Time Disease Prediction and Risk

Mapping in Shrimp Aquaculture Using IoT-Integrated LSTM Deep Learning Frameworks." *National Journal of Smart Fisheries and Aquaculture Innovation* 2, no. 1 (2024): 19-27.

[14] Tanner, Lloyd, and Andrew Bruce Single. "Animal models reflecting chronic obstructive pulmonary disease and related respiratory disorders: translating pre-clinical data into clinical relevance." *Journal of innate immunity* 12, no. 3 (2020): 203-225.

[15] Wang, Qi, and Sha Liu. "The effects and pathogenesis of PM2. 5 and its components on chronic obstructive pulmonary disease." *International journal of chronic obstructive pulmonary disease* (2023): 493-506. https://doi.org/10.2147/COPD.S402122

[16] Zhang, Zili, Jian Wang, and Wenju Lu. "Exposure to nitrogen dioxide and chronic obstructive pulmonary disease (COPD) in adults: a systematic review and meta-analysis." *Environmental Science and Pollution Research* 25, no. 15 (2018): 15133-15145.

[17] Zhong, Zihang, Hui Yu, Yafei Wang, Xinxin Kong, Ruyu Huang, Jiong Li, Yang Zhao et al. "Dynamic associations between long-term exposure to ambient air pollution and respiratory-cardiovascular diseases: A trajectory analysis of a prospective study." *Ecotoxicology and Environmental Safety* 306 (2025): 119329. https://doi.org/10.1016/j.ecoenv.2025.119329