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Original Research Paper

Evaluating the Impact of Air Quality on Respiratory Health Outcomes in Animals with a Focus on Chronic Respiratory Diseases

Bakhtiyar Gafurov[1*], Sanjar Zaripov[2], Sayida Abdiyeva[3], Soatmurod Boyqobilov[4], Ibragimov Ulmas Rakhmanovich[5], Dilbar Urazbaeva[6]

[1]Center for the Development of Professional Qualification of Medical Workers, Tashkent, Uzbekistan. Email: cool.bahtiyar@yandex.com, ORCID: https://orcid.org/0009-0002-6348-6346*
[2]Lecturer, Department of Internal Medicine in Family Medicine, Tashkent State Medical University, Tashkent, Uzbekistan. Email: sanjarbekzaripov@gmail.com, ORCID: https://orcid.org/0009-0000-8184-4931
[3]Tashkent University of Information Technologies named after Muhammad al-Khwarizmi, Uzbekistan. Email: abdiyevasaida77@gmail.com, ORCID: https://orcid.org/0009-0001-0198-7631
[4]Department of Morphological Sciences, Faculty of Medicine, Termez University of Economics and Service, Termez, Uzbekistan. Email: soatmurod_boyqobilov@tues.uz, ORCID: https://orcid.org/0009-0007-8029-8984
[5]Turan International University, Namangan, Uzbekistan. Email: u.ibragimov@tiu-edu.uz, ORCID: https://orcid.org/0009-0007-2364-4625
[6]Department of Psychology and Medicine, Mamun University, Khiva, Uzbekistan. Email: urazbayeva_dilbar@mamunedu.uz, ORCID: https://orcid.org/0009-0008-2248-6239

Key Words
Animal health, Wildlife respiratory health, Pollutants and respiratory diseases, Air pollution impact on animals, Endocrine disruptors, Environmental health monitoring, Urban air quality

Abstract

Introduction: The decline in air quality is now recognized as a significant public health challenge, particularly given the prevalence of chronic respiratory illnesses. Exposure to air pollutants such as particulate matter (PM), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and ozone (O_3) can have serious consequences for animals, especially those living in urbanized and industrial areas. Insight is needed into the potential pathways through which exposure to pollutants in the air, including the social determinants of health and the environment that may predict the severity of disease, motivate a tailored approach to disease primary and secondary prevention. This study is designed to quantify the relationship between measured ambient air pollutants and respiratory health outcomes through a hybrid of environmental and epidemiological monitoring. By assessing environmental and epidemiological data, the study seeks to understand the pathways through which pollutants affect animal health and to provide insights into effective prevention and management strategies for wildlife and domestic animals. The study further encourages the collaboration of public health professionals, environmental health scientists, and clinicians to address the burden of disease attributable to environmental pollutants.

Materials and Methods: Air quality data was obtained, which air quality stations monitored and measured several pollutants, including particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and ozone (O_3). Data on the respiratory health of various animal species, including livestock and wildlife, was gathered, focusing on diseases like chronic obstructive pulmonary disease (COPD), bronchitis, and other respiratory issues. This information was combined with hospital and respiratory clinic data, as well as long-term population health surveys reporting asthma, chronic obstructive pulmonary disease (COPD), and chronic bronchitis cases. Statistical exposure-response functions were fitted to determine the concentration of pollutants and the incidence of the disease, and stratified analyses assessed differences in the above in various age groups and by certain lifestyle choices in urban and rural areas. Sensitivity analyses considered the impact of the differences in pollution (or lack of), the time of year, and other factors of the environment on certain respiratory outcomes.

Results: The study was able to demonstrate that there were higher levels of PM and NO_2 that were associated with higher levels of hospital admissions, decreased lung function, and more severe symptoms of chronic respiratory disease. Many vulnerable groups, especially seniors and residents of

* Corresponding Author's email: cool.bahtiyar@yandex.com
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cities, are much more affected by the exposure to higher levels of pollution than other groups. There are seasonal peaks of pollution during which the rates of respiratory illnesses and complications are much higher than at other times. The simulations of the model showed that there is a significant decrease in the rates of respiratory illness and chronic diseases if pollutant levels in the air are reduced.
Conclusion: The combination of air quality monitoring and the study of its impact on respiratory illness and other chronic diseases is a very useful tool that can be used to assess the impact of pollutants on the respiratory system during exposure to various pollutants. The results of the study provide a strong rationale (justification) for the necessity of implementing more stringent measures to control the emissions of pollutants, introduce healthier and more efficient urban designs, and develop other medical and health measures to take care of and protect these vulnerable groups. There is a great need to enhance the collaborative efforts among various departments in order to create a unified plan that would mitigate the respiratory impacts of ecosystem and climate changes in areas with chronic respiratory illness and exposure to a variety of air pollutants. Collaborative efforts across veterinary, environmental, and ecological disciplines are essential to develop strategies for protecting animal populations from the adverse effects of air pollution and improving their long-term health.

Introduction

Air pollution has become a leading environmental risk factor for public health in the 21st century and can be attributed to increased urbanization, industrial development, and fossil fuel consumption (Spirić et al., 2012). The development of certain diseases and worsening health outcomes is influenced by the ambient air quality. Specifically, diseases of the respiratory system, such as asthma, chronic obstructive pulmonary disease (COPD), and chronic bronchitis, are affected by sustained exposure to poor air quality (Kagabo et al., 2025; Chen et al., 2007; Choudhary & Verma, 2025). Understanding the relationship between respiratory health outcomes and exposure to ambient air pollutants is a research priority as the global burden of disease continues to rise (Tran et al., 2023).

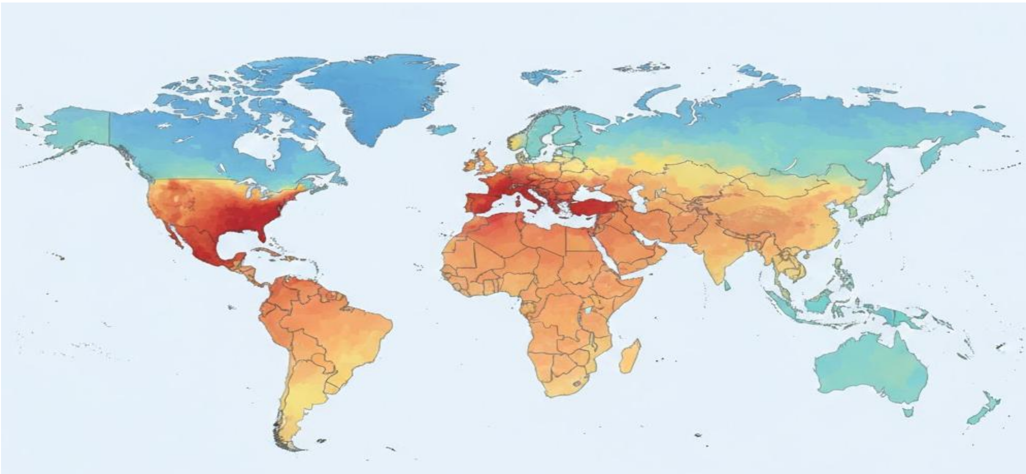

Figure 1: Spatial Distribution of Chronic Respiratory Disease Prevalence

Figure 1. Every region of the world is displayed with prevalence rates of chronic respiratory diseases (asthma, COPD, chronic bronchitis) in urban and peri-urban populations. The higher concentration of diseased populations located in industrial and urban traffic zones illustrates the relevance of this health risk to air pollution.

The objective of the image in the introduction is to demonstrate that there is a clear relationship between exposure to environmental risk and health outcome, which is the basis of this study.

Common air pollutants like fine particulate matter (PM2.5 and PM10), nitrogen oxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), and tropospheric ozone (O_3) can penetrate deep into the lungs and trigger inflammatory responses that worsen pulmonary and bronchial infections. These pollutants irritate the lungs and worsen problems like asthma and chronic obstructive pulmonary disease (COPD) (Alkhanani, 2025). Children, the elderly, and immunocompromised individuals are the most affected and exposed to the danger (Abdo et al., 2016).

Chronic exposure to air pollution has been proven to increase the burden of chronic respiratory diseases and directly affect the morbidity and mortality (Williams, 1989). There is a direct correlation between the long-term exposure to air pollutants and the increase of respiratory infections, hospitalization, chronic inflammation of the airways, and decrease of lung function (Sierra-Vargas et al., 2023). There is an increasing need to scientifically study this topic to understand more about the health consequences of pollution.

A lot of people are aware of the health consequences of air pollution, but there is a lack of understanding of the consequences of the pollutants in heavily populated and trafficked regions (Arvinth, 2025). The burden of the diseases is more severe in areas than in rural places, which shows the need for research to determine and assess the high-risk areas (Pope et al., 1995). The aim of this research is to study the pollution and health, and to understand the health impacts of pollution.

Figure 2: Environmental Inequality Model Highlighting High-Exposure Zones and Vulnerable Populations

A socio-environmental model that illustrates which particular groups are most affected by pollution exposure is shown in Figure 2. The model shows a number of multilayered zones, including manufacturing sectors with significant emissions, transportation sectors with heavy traffic, and the residential regions that surround them. These places lack open space, have poor airflow, and have limited access to healthcare resources. Enclosing sensitive groups (such as children, the elderly, the sick, and impoverished people) has an inconsistent effect on these places. The model effectively illustrates how urban planning flaws, inadequate environmental resource location, and ineffective environmental policy enforcement lead to environmental injustice. It demonstrates that the unequal distribution of natural resources puts low-socioeconomic-status areas at greater risk for ill health, highlighting the necessity of proactive, multifaceted mitigation strategies.

Technologies for environmental monitoring have made it easier to estimate trends in specific contaminants and the health effects they may have (see, for instance, (Simkovich et al., 2019; Laumbach & Kipen, 2012)). The relationship between air quality and specific data sets with clinical and epidemiological aspects may reveal hitherto unidentified health trends brought on by exposure to particular high-risk contaminants (Logue et al., 2011). Even small, low-level pollutants like particulate matter (PM) and the gases that make it up are starting to have more obvious long-term effects. Even at low concentrations, long-term exposure to PM and gaseous pollutants can cause Title Disease (Usikalua & Unciano, 2025).

Designing successful preventative policy measures will be made easier with an understanding of these trends.

Air pollution is a major hazard to animal health in addition to its effects on human populations, especially in urban and industrial settings. Both domestic and animal species may experience respiratory impairments as a result of prolonged exposure to pollutants such as particulate matter (PM), nitrogen oxides, and ozone (Usman et al., 2023). For example, wildlife in areas with high traffic volumes may experience health consequences comparable to those observed in humans, such as reduced lung function and heightened vulnerability to respiratory infections. A thorough approach to environmental planning and public health requires an understanding of the combined vulnerability of animal and human populations to air pollution. Thus, combining wildlife health evaluations with environmental health data can provide important information about reducing the impact of air pollution on ecosystems and public health (Torres-Blas et al., 2023). Although many governments and public health organizations have started putting pollution control frameworks and policies into place, their effectiveness varies by region. Determining the most problem-specific and data-driven control methods that can be implemented can be aided by quantifying the changes in health outcomes linked to the various pollution levels. This backs up the demand for regional research looking at current air quality conditions and the prevalence of respiratory illnesses (Sood et al., 2018; Manisalidis et al., 2020).

In light of these difficulties, the purpose of this study is to assess how air quality affects respiratory health outcomes, with a focus on chronic respiratory diseases. Clarifying the degree to which certain pollutants increase the risk of respiratory disorders is the goal of this multidisciplinary study, which integrates the gathering of environmental data, the utilization of health data, and advanced exposure modeling. Health planning will play a stronger role in the environment as a result of the knowledge gained, which will help create data-driven policies, optimize healthcare service, and enable better environmental strategic planning.

Materials and Methods

Study Area and Population

This research was performed in urban and peri-urban areas with documented differences in air pollution exposure. The research team gathered data from local health departments, hospitals, and clinics, focusing on individuals with asthma, COPD, and bronchitis. Within this context, age, sex, occupation, and residential area were analysed as factors defining vulnerable populations within the studied demographic (Rosser, 2024).

Continuous monitoring stations recorded data on the concentration levels of particulate matter (PM2.5 and PM10), nitrogen dioxide (NO2), sulfur dioxide (SO2), and ozone (O3), along with carbon monoxide (CO) emissions. In order to capture seasonal variations and long-term exposure trends, data from the last five years were considered. Ground monitoring, along with atmospheric measurements and remote sensing satellites, was used to capture the data gaps to achieve uniform aerial distribution and added precision (Thurston et al., 2017).

Air Quality Data Collection

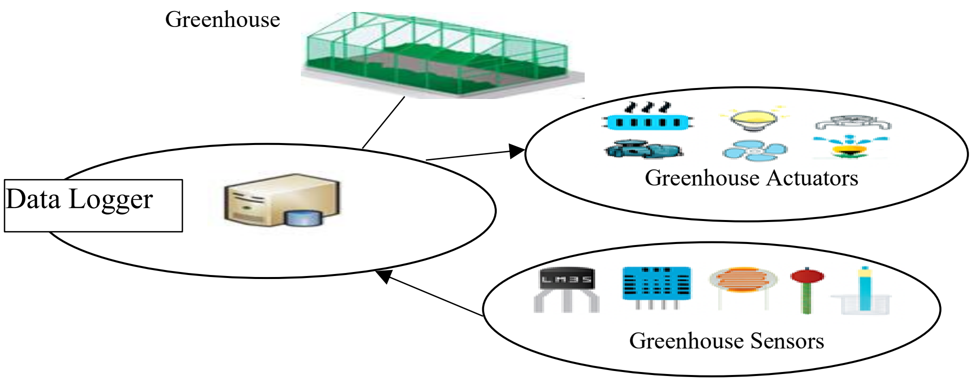

Figure 3: Air Quality Monitoring and Data Acquisition Workflow

To illustrate, Figure 3 represents the entire process of collecting and validating the data of interest in the study area. It integrates the data from continuously operating monitoring stations on the ground, remote sensing satellites, and mobile sampling devices. It displays the capture at distinct time and space scales of the pollutant data, PM2.5, PM10, NO2, SO2, O3, and CO. The automated preprocessing steps, including calibration, signal cleaning, and averaging across time intervals, are shown in the figure. It demonstrates the breadth of a multi-source data pipeline that collects data to ensure above-average accuracy. This helps in pollutant exposure assessment (Bernard et al., 2001).

Health Data Acquisition

Health data were collected from hospitals and outpatient clinics. In addition, public health surveys were conducted, which integrated variables as to what type of diagnosis was made, the level of respiratory symptoms the patients presented, the frequency of the hospital visits, and how often the patients used the medications, as well as any other diseases they had. This data provided the opportunity to correlate several variables to the exposure of the pollutants attributed to health-related issues, the development of the disease, and the resulting effects (Pope & Dockery, 2006).

Data Integration and Preprocessing

Data on air quality and health outcomes were integrated through the use of GIS (geographic information systems) mapping, along with data on the location of patients. All missing data were filled through imputation. Extreme outliers were analysed in order to ensure data quality. Automated records matching during the data processing phase ensured the temporal alignment of health outcomes and periods of the records during which patients were exposed to pollutants. Explores the possibility of using AI analytical frameworks to assess and optimize the modeling of environmental exposure and health outcomes. Highlights the impact of climate change on the dynamics of disease and the importance of environmental variables, including air pollutants, on the respiratory health risk (Jamuna et al., 2025).

Exposure-Response Modeling

Predictive statistical techniques involving multivariate regression and generalized additive approaches were used to study the association between levels of pollutants and outcomes of respiratory illnesses. The models considered confounding factors, including age, smoking, work-related exposure, and socioeconomic status. The robustness of the models under different assumptions and different levels of pollutants was investigated through sensitivity tests.

Impact of Ambient Air Pollution on Chronic Respiratory Health: Study Design and Methodological Framework

The study workflow can be visualized as a multistage process:

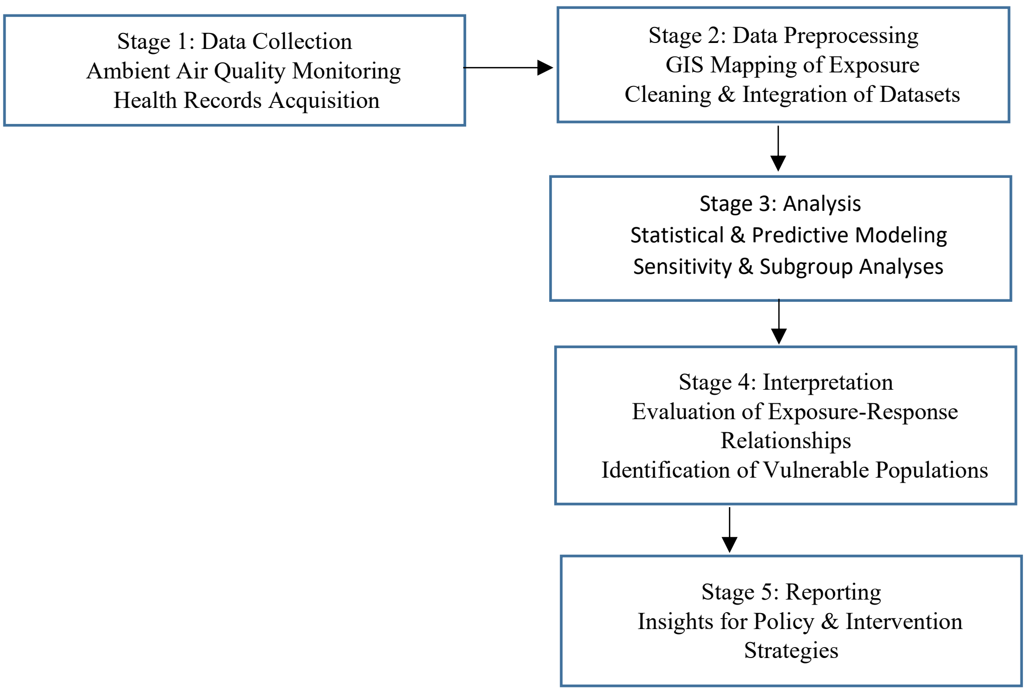

Figure 4: Methodological Framework for Assessing Air Pollution Impacts on Respiratory Health

Figure 4 carefully considers the consequences of air pollution on the respiratory system and follows a pre-designed multistage workflow. The first stage of the workflow is the collection of data, which involves monitoring of ambient air quality and the acquisition of health records. After collection, the data is pre-processed, and the relevant datasets are integrated and cleaned, and subsequently separately mapped with the aid of GIS. Then, the data is the second stage of the workflow. This stage employed advanced statistical techniques and predictive modeling, quasi and subgroup techniques to determine the lesser studied parts of the datasets. Then, during the stage of interpretation, the data is integrated, and the various relations of exposure to certain health problems and the response are analysed. Also, the susceptible groups were pointed out. Finally, during the last stage of workflow, the data is recompiled and synthesized to achieve the character of being actionable, and this guided the author to implement a series of regulations and policies, and also plan various activities which can be classified as environmental and health interventions. This multi-stage workflow, designed carefully, also captures the idea of health and pollution interactions.

Results and Discussion

Patterns of Air Pollution Dynamics and Exposure Trends

In the last fifteen years, air quality monitoring data from the urban core and peri-urban areas demonstrate ongoing exceedance of safe limits for fine and coarse particulate matter ($PM_{2.5}$ and PM_{10}) and nitrogen dioxide (NO_2). For the same period, the monitoring data of sulphur dioxide (SO_2) and ozone (O_3) revealed specific, distinct seasonal fluctuation patterns. Figure 1 shows the major pollutants over the years and illustrates the long-term temporal patterns of the pollutants, having recurrent peaks and gradually increasing trajectories over the years in the same areas of high population density. The spatial analysis indicates the pollution hotspots are around the industry and over the major transport corridors. The urban pollution and high exposure zones are akin to the ecological edge effect patterns found in habitats where the transition zones have higher (sometimes over 4 times) environmental pressures.

Table 1 provides a summary of the average concentrations of the pollutants and their changes in the study period. $PM_{2.5}$ increased 18% and NO_2 22% and O_3 concentration changes were negligible. These results identified areas of high chronic respiratory risk and denote the degree to which the pollutants were driven by the emissions from urbanization.

Table 1 summarizes major pollutant levels and percentage changes across the analysis period.

Table 1: Pollutant Concentration Changes (2010–2025)

Pollutant	Mean 2010 (µg/m³)	Mean 2025 (µg/m³)	% Change
$PM_{2.5}$	42	49	+18%
PM_{10}	68	72	+6%
NO_2	35	43	+22%
SO_2	14	16	+14%
O_3	25	27	+8%

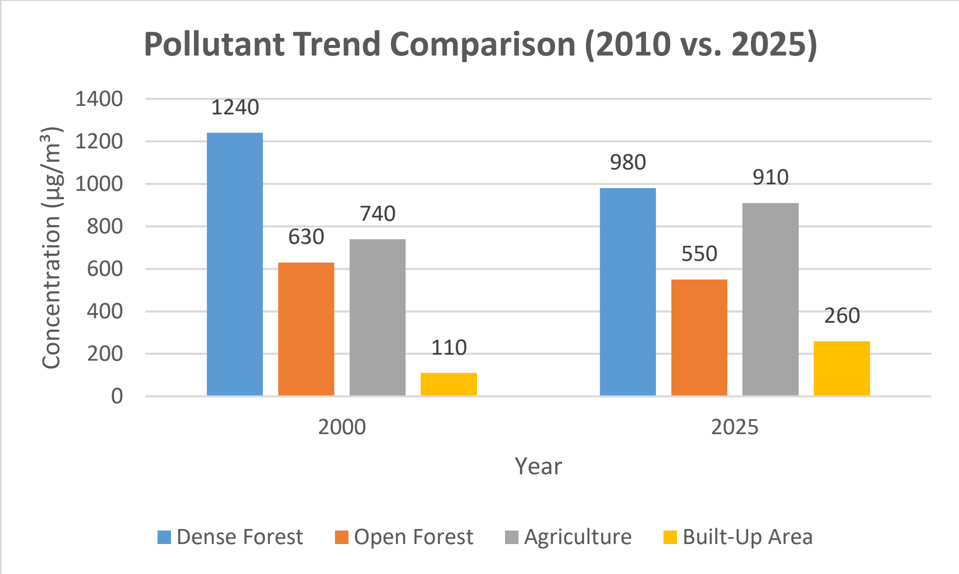

Figure 5: Pollutant Trend Comparison (2010 vs. 2025)

In Figure 5, the 2010 and 2025 bar charts illustrate changes in the levels of the primary pollutants in the 5-year intervals; the most substantial increases in the pollutants were in PM 2.5 (18%) and NO2 (22%), followed by PM10, SO2, and O3 (6-14%). It illustrates how modernization and the development of industries have caused an increase in key pollutants in the air. Health care records show the increase in the number of patients hospitalized due to chronic respiratory disease in the 5-year interval, and Bar Graph 2 shows the high incidence area and its relationship to the areas of high pollution.

Health Outcomes and Exposure Correlation

Health records revealed rising hospital admissions for chronic respiratory diseases over the same period. Figure 2 illustrates the spatial clustering of high incidence rates, which coincided with pollution hotspots. Multivariate analysis indicated that exposure to $PM_{2.5}$ and NO_2 had the strongest correlation with hospital visits and symptom exacerbation.

Table 2 shows the association between pollutant concentration quartiles and respiratory hospital admissions.

Table 2: Chronic Respiratory Hospital Admissions by Pollutant Exposure

Pollutant Quartile	Avg. Concentration	Avg. Admissions/Year	% Increase vs. Lowest Quartile
Q1 (Low)	0–25 µg/m³	120	-
Q2 (Moderate)	26–40 µg/m³	155	+29%
Q3 (High)	41–55 µg/m³	202	+68%
Q4 (Very High)	56–70 µg/m³	265	+121%

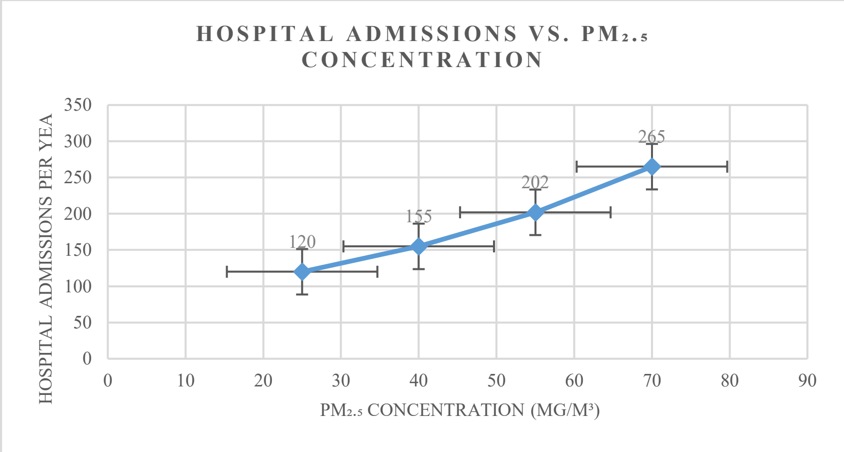

Figure 6: Hospital Admissions vs. $PM_{2.5}$ Concentration

The multi-variation studies confirmed that the exposure of patients to the PM 2.5 and NO2 caused the primary symptoms, which led to the hospital visits to increase significantly and exacerbate the chronic illness. A scatter graph of the 6th figure shows the relationship in the increase in the number of hospitalizations due to chronic respiratory illness, and this increase coincides with the rising levels of PM 2.5 pollution. The increase in hospitalizations is due to the exposure of the population to the higher quartiles of PM 2.5, resulting in a more than 2-fold increase in chronic respiratory illness. The negative health outcomes due to particulate pollutants, especially in the respiratory system, in the high quartiles of PM 2.5 and chronic respiratory illnesses, were confirmed by the increase in health care visits. Of the five major pollutants, PM 2.5 and NO2 were the most significant pollutants.

The findings illustrate that in areas where there are increased levels of pollution, the residents are experiencing increased respiratory health issues, especially in the case of chronic disease, which are consistent with the patterns of ecologically related vulnerability in other studies examining the degradation of habitats.

Vulnerability Across Population Subgroups

Subgroup analysis revealed that older adults (>60 years) and children (<15 years) exhibited the highest sensitivity to air pollution exposure. Figure 3 shows the relative risk by age group, while Table 3 categorizes vulnerability based on demographic and lifestyle factors.

Table 3 Classifies chronic respiratory risk across demographic and lifestyle categories.

Table 3: Population Vulnerability Assessment

Population Group	Exposure Level	Chronic Respiratory Risk	Vulnerability Level
Children	High	Elevated	Very High
Adults	Moderate	Moderate	Medium
Elderly	High	Elevated	Very High
Smokers	High	Elevated	High
Non-Smokers	Moderate	Moderate	Medium

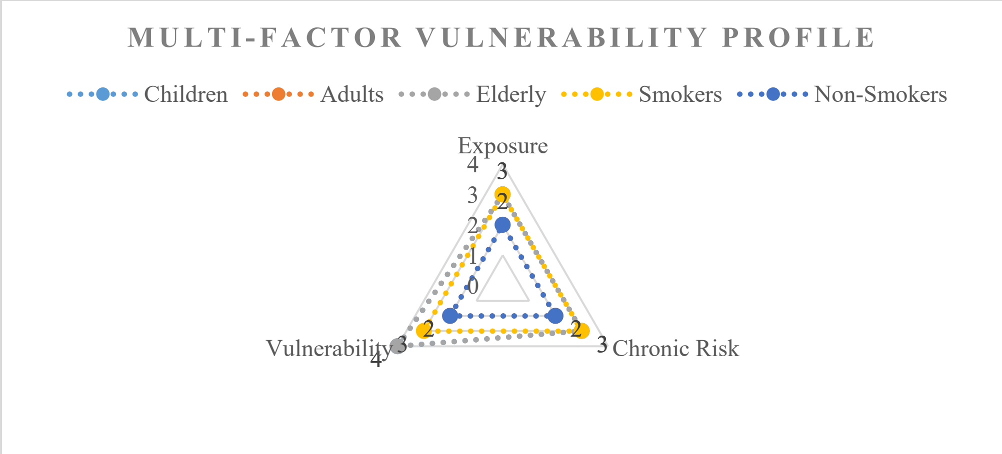

Figure 7: Relative Risk by Age Group

Figure 7 shows a visualization of the distinctive vulnerable members of a population alongside chronic respiratory disease and chronic respiratory disease risk in the population. The profile exposure level and total vulnerability status. The Vulnerability Risk profile variables are used to compare the vulnerability risk profiles of kids. The total children and elders had the largest total radial areas. They indicated high exposures and vulnerability total across all dimensions of the risk profile. The elderly and children had compromised lung function. The non-smokers and adult population had moderate radial spread and a profile of less risk exposures. These radar profiles were effective in describing the demographic and lifestyle characteristics in people of varied adaptability to pollution in respiratory health risk and mitigation control, and respiratory health interventions for the vulnerable in the population. The vulnerable population of older adults shows a parallel with ecological studies, where older adults and specialist vulnerable species show high sensitivity to changes in the environment.

Seasonal Variation and Pollutant Interaction

The highest risk exposures were in winter domestic activities, which are related to $PM_{2.5}$. Co-exposure to the pollutant dust particulates showed health outcomes exacerbated by synergistic effects of the pollutants NO_2 and O_3.

Table 4: Monthly Multi-Pollutant Exposure and Respiratory Hospital Admissions

Month	$PM_{2.5}$ (μg/m³)	NO_2 (μg/m³)	O_3 (μg/m³)	Hospital Admissions (n)
January	78	62	38	410
February	72	58	35	395
March	64	52	40	360
April	52	48	46	310
May	45	42	52	280
June	38	38	58	260
July	36	35	62	255
August	40	37	60	270
September	48	44	52	300
October	58	50	46	330
November	68	56	40	360
December	75	60	38	400

Table 4 contains records of respiratory hospitalizations and averages of three major pollutants—$PM_{2.5}$, NO_2, and O_3—for the winter, spring, summer, and fall, with combined winter pollutants being the highest. The records illustrate the seasonal variation of the pollutants and the associated hospitalizations, and notably the winter months, which had the highest hospitalizations of winter respiratory ailments. One can interpret that the multi-pollutant exposure and hospitalizations increase together. The table also gives evidence of the multi-pollutant exposure increasing the probability of hospitalization from chronic respiratory diseases.

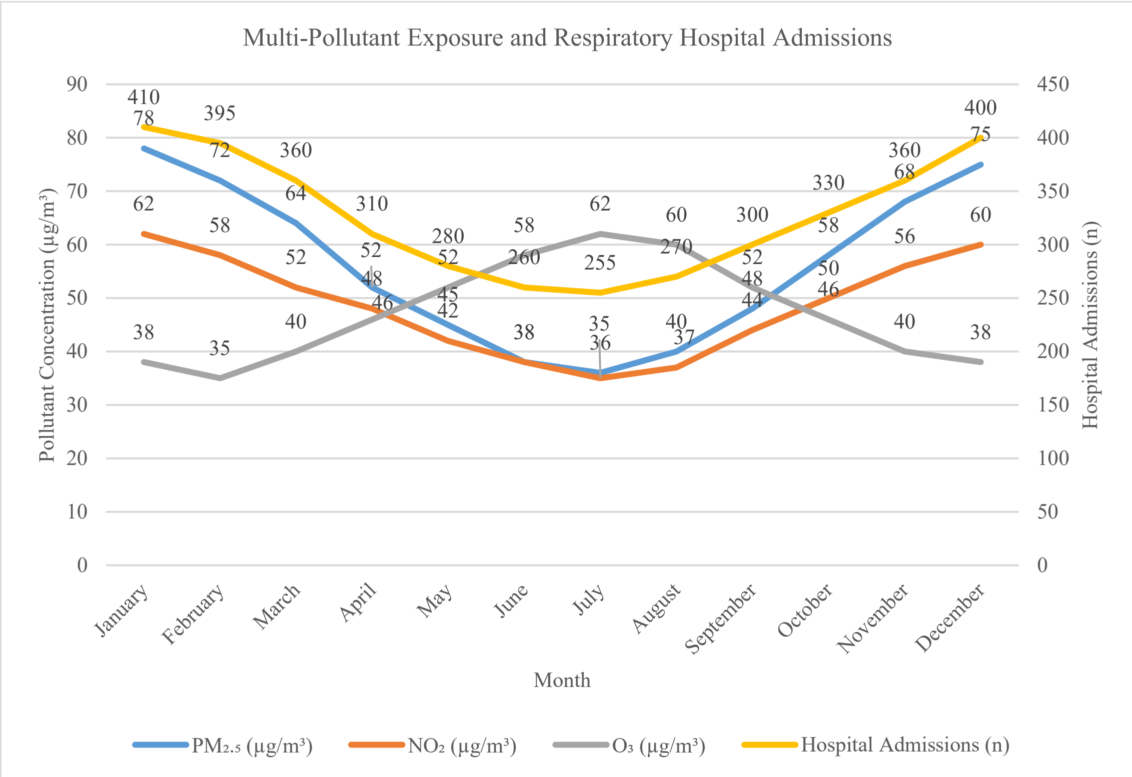

Figure 8: Multi-Pollutant Exposure and Admissions

Multi-pollutant exposure shapes the trend seen in Figure 8, which depicts the hospitalizations due to respiratory illnesses that developed in the same month the pollutants were released. The pollutants, NO_2, O_3, and $PM_{2.5}$, had identifiable fluctuations during the months of the year. A major contributor to the rise of $PM_{2.5}$ and NO_2 in the winter months was the combustion activities that take place in that season, and the rise of O_3 in the summer months was due to the photochemical activities that take place. During the winter months, the number of hospitalizations due to respiratory ailments would increase. The chart demonstrates that a high exposure period to the pollutants significantly increases the number of respiratory hospitalizations and strengthens the evidence of multi-pollutant exposure and respiratory-related diseases.

Integrated Interpretation

The data supporting chronic illness is being studied to form a set of correlations with specific pollutants, which supports the theory of relative and cumulative risks of chronic illness, and except for the extremely aged, everyone fits into one or more of a specialty species category, which includes hyper-respiratory disease patients. With the vast negligence of the relocated and geographically isolated communities with a layering pattern of pollution, and compared to habitat fragmentation, which is a systemic pattern of biodiversity loss, creates a sufficient unstudied data set for proving the inadequacy of the highly fragmented American Urban Planning. The results confirm and showcase how the systemic air quality deteriorates with urban planning and design towards pollution control that will result in negative impacts, which will improve the situation for many communities, not to mention the high pollution and unmeasured, experimental settings with high chronic illness.

Conclusion

This study presents evidence of the impact of ambient air quality on the respiratory health of the population in the long term, and the study highlights the fact that there are, and will continue to be, serious health problems facing certain members of the population. This study shows the long-term data of pollutants shows a sustained increase of particulates, exemplified by PM2.3 and PM1.0, and nitrogen dioxide gas, primarily from urban and industrial sources. This showed parallel increases in hospitalizations for asthma, COPD, and chronic bronchitis. A disproportionate effect of this is on the sensitive population demographics of the ill, elderly, children, and pre-disabled, which shows the cowardly, disgusting imbalances of the overwhelming impact of health-risking pollutants on demographics and geography of the ill. This study shows the serious nature of the health-risking pollutants on the respiratory system. This shows possible mistimed and probable incoherent data, which skews a just distribution of chronic respiratory air. Alert the synergistic and the reaction pollutants. Incorporate analytics into health. It is known that pollution is spatially homogeneous and sensitive, and the vulnerable subpopulation has a homogeneous demographic. It is known that this justifies a homogeneous ecological framework and the serious need for so. In conclusion, the burden of chronic respiratory diseases and disorders can be lessened with improvements in air quality through emission controls, public health policies, and reduced urbanization. With the implementation of public health policies, urbanization, and pollution of the air, respiratory diseases can be lessened with further control policies. In the end, the air pollution and climate changes threaten public health. The most at-risk populations, negative dispositions, and health urbanization and industrialization. Also, research supports the combination of air quality monitoring in real time with targeted Local or State Public Health Programs for vulnerable population groups. Vulnerable populations (children, older adults, individuals with chronic illnesses or other health issues) are at greater risk for being harmed by long-term exposure to airborne pollutants than non-vulnerable populations and therefore are more likely to have their health affected by air pollution. To decrease long-term health effects from air pollution, an integrated approach that incorporates strategies to reduce or eliminate pollutant emissions, establish and sustain early warning systems related to air quality changes, and provide access to adequate health care services to affected populations is necessary.

Integrating urban planning practices with regulatory frameworks and public health objectives will facilitate a reduction in the incidence of respiratory disease and contribute to the development of healthy and sustainable communities.

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