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Original Article

Environmental Determinants of Chronic Obstructive Pulmonary Disease: The Role of Air Pollutants in Hospitalization Trends

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Abstract

Background: Air pollution is an important global public health concern with multiple consequences for the individuals with respiratory diseases. We aimed to assess the influence of air pollution variables on the hospitalization rates of individuals with chronic obstructive pulmonary disease (COPD).

Methods: Atmospheric pollutant parameters, such as NO_2, SO_2, CO, O_3, $PM_{2.5}$, PM_{10}, and AQI, from Mar 2022 to Mar 2024 were measured. The information of COPD patients was extracted from Masih Daneshvari Hospital (referral center for respiratory diseases in Tehran). The relationship among data, Relative Risk (RR), and Attributable Proportion (AP) for prolonged exposure to air pollutants during a biennial period was assessed using the Air Quality Plus (2.2.4) software.

Results: March 2023 saw the highest number of hospitalizations, with an average of 4.16 cases. This was concurrent with an elevation in $PM_{2.5}$ concentrations. Furthermore, the month of Aug 2023 exhibited a high hospitalization rate, with an average of 3.8 cases, linked to the rise in the concentration of $PM_{2.5}$, NO_2, and O_3 air pollutants. The highest mean relative risks (RRs) associated with acute exacerbation of COPD were as follows: (PM_{10}: 1.83, $PM_{2.5}$: 1.76).

Conclusion: High levels of air pollution, specially $PM_{2.5}$, significantly worsen COPD conditions and are a main trigger for COPD exacerbation. Consequently, enforcing more stringent air quality regulations is an essential public health approach to alleviate the incidence of COPD.

Keywords: Air pollution; Air quality index (AQI); Relative risk

Introduction

Air pollution has emerged as a principal worldwide environmental hazard, presenting significant risks to human health and ecosystems (1). The WHO designates it as the foremost environmental health hazard, linked to a broad range of detrimental effects, encompassing cardiovascular, metabolic, and diverse respiratory disorders (2,3). Chronic

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Obstructive Pulmonary Disease (COPD) is significantly impacted, ranking as the fourth largest cause of mortality worldwide and anticipated to ascend to third place by 2030 (4). COPD, an inflammatory pulmonary condition that includes chronic bronchitis and emphysema, significantly increases patients' susceptibility to environmental contaminants. A significant amount of research indicates that exposure to ambient air pollution, especially due to fast urbanization, adversely affects lung function, precipitates exacerbations, and heightens the risk of hospitalization for persons with COPD (5-7). Notwithstanding this recognized correlation, significant deficiencies persist in comprehending the quantitative link between certain ambient contaminants and COPD-related hospitalizations in various metropolitan environments. The current research examines the relationships between hospitalization rates among COPD patients in metropolitan areas and ambient air pollution levels in order to close this gap. Using high-resolution epidemiological and environmental monitoring data, we concentrate on important pollutants such as sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), carbon monoxide (CO), fine particulate matter ($PM_{2.5}$), and (PM_{10}). In order to provide data to support focused public health initiatives and air quality management, we seek to quantify the strength and temporal patterns of these connections.

Tehran, Iran's capital, is located on the southern slopes of the Alborz Mountains at an elevation of 1,190 m (35.7°N, 51.5°E), spanning 73 km in width. Over recent decades, rapid population growth, a surge in motor vehicle numbers, and land-use/land-cover changes have dramatically escalated air pollution levels, threatening both ecosystems and human health. The city's mountainous barrier severely restricts natural ventilation, intensifying winter temperature inversions and the impacts of Middle Eastern dust storms, rendering Tehran one of the world's most polluted metropolises (8-10).

European Centre for Environment and Health of the WHO has developed a tool known as AirQ+. It is intended to assess the correlation between health outcomes and air pollution exposure (11). The level of exposure to ambient PM or NO_2 is connected with daily mortality, mostly from cardiovascular and respiratory disorders (12,13). Individuals with COPD may have heightened risks of acute exacerbations, emergency department visits, hospitalizations, and death due to exposure to air pollution (14-16).

Material and Methods

Pollution Data

From Mar 21, 2022, to Mar 20, 2024, 26 monitoring stations situated in various regions of Tehran were used to collect daily air pollution measurements, including carbon monoxide (24-hour average in ppm), particulate matter smaller than 2.5 μm (24-hour average in μg/m3), particulate matter under 10 μm (24-hour average in μg/m3), nitrogen dioxide (24-hour average in ppm), Sulphur dioxide (24-hour average in ppm), ozone (24-hour average in ppm), and AQI. The Tehran municipality's website provides information on air quality reports.

COPD data

This research was performed in Tehran, Iran. Data on patients admitted with a verified diagnosis of chronic obstructive pulmonary disease (COPD) were obtained from Masih Daneshvari Hospital, a prominent referral center for respiratory ailments. During this timeframe, 1,985 instances of COPD were documented. A total of 901 hospitalizations with COPD were documented among inhabitants of Tehran. Due to restricted availability to city-wide population data, the research concentrated on hospitalization frequency rather than population-based rates. Patients were eligible for inclusion provided they had a verified COPD diagnosis, were admitted to Masih Daneshvari Hospital during the research period, and were permanent Tehran residents. Patients with cancer, severe cardiovascular disease, or other chronic respiratory illnesses that may confuse COPD-related outcomes were eliminated, as were those who did not live in Tehran.

AirQPlus

AirQPlus is a software instrument that was developed by the WHO to evaluate the health consequences of air pollution. The relative risk of health outcomes associated with exposure to contaminated air is one of the primary results provided by AirQPlus (17). AIRQ+ uses the attributable proportion (AP) to calculate the impact of air pollution to death and morbidity. The AP is computed as:

$AP= \Sigma (RR-1) \times P / \Sigma (RR \times P)$

P represents the proportion of the population in exposure and RR the corresponding relative risk (18). To determine the relative risk of hospitalization among COPD patients as a result of exposure to a variety of air pollutants, we used AirQPlus software. $PM_{2.5}$, PM_{10}, NO_2, and O_3 were the pollutants that were analyzed. In order to assess the RR, we entered the annual average concentrations of the pertinent pollutants (μg/m3) and the number of COPD patients hospitalized in 2022 and 2023. Before being employed in the analysis, pollutants with PPM units were converted to micrograms per cubic meter (μg/m3).

Statistical analysis

The average air pollution levels from all 26 sites were used in the statistical models to reflect the pollution level for the whole city. A statistical study was performed on all parameters associated with the concentrations of ambient air pollutants, including $PM_{2.5}$, PM_{10}, CO, NO_2, SO_2, O_3, and AQI. The hospitalization rate and the monthly average of each pollutant were studied by descriptive statistics, regression analysis, and correlation research. The study used time series plots to examine the average concentrations of air contaminants in different months (19). Software tools like GraphPad Prism 8, SPSS 27, and MINITAB 21 were used for data analysis. The SRplot web server was used to generate some plots (20).

Ethics Statement

The Ethics Committee of the Institutional Review Board of Shahid Beheshti University of Medical Sciences, Tehran, (Ethics Code: IR.SBMU.NRITLD.1403.085) approved the study.

Results

Characteristics of the patients and air pollution

Overall, 1985 patients with chronic obstructive pulmonary disease (COPD) were admitted to Masih Daneshvari Hospital, Tehran, Iran. Of them, 901 patients who lived in Tehran were the subject of our investigation. Of these patients, 21.64% were female, and 78.35% were male. The mean age of the patients admitted to the hospital was 67.63 yr. The mean daily values of PM_{10} and $PM_{2.5}$ were recorded at 67.28 μg/m³ and 94.38 μg/m³, respectively, for the period from 2022 to 2024 (as shown in Table 1). The measured concentrations are higher than the WHO limits, which are 50 μg/m³ for PM_{10} and 25 μg/m³ for $PM_{2.5}$ (21). Male patients outweigh female patients, and the greatest frequency of COPD is seen in those over 60. Fig. 1 illustrates monthly hospitalizations for COPD for smokers and non-smokers from Mar 2022 to Mar 2024. Smoking is a major risk factor, as shown by the fact that smokers are more likely than non-smokers to be hospitalized. Hospitalizations for nonsmokers are more consistent over the course of months, indicating that other factors (such as infections, temperature, or air pollution) affect their trends. Seasonal increases, particularly during the winter, lend credence to the idea that smoking and air pollution contribute to exacerbations of COPD.

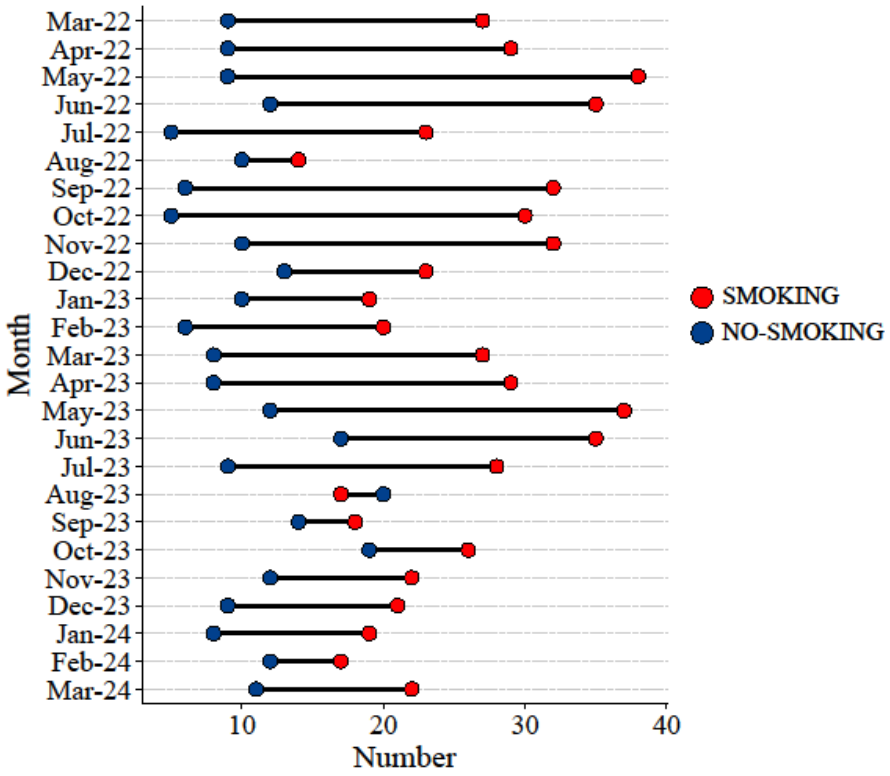

Fig. 1: Distribution of smokers and nonsmokers patients

Table 1: Descriptive statistics of daily air pollutant concentrations and Air-Quality Index (AQI), Tehran, Mar 2022 – Mar 2024

Variable	Minimum	Maximum	MEAN ± SD	Median (IQR)
Air pollutant concentrations				
CO (ppm)	21.48	41.57	30.57 ± 5.96	29.53
O_3 (ppm)	10.65	110.3	45.16 ± 30.80	37.55
SO_2 (ppm)	12.16	36.23	20.82 ± 6.17	20.37
NO_2 (ppm)	54.48	82.87	65.40 ± 7.336	64.42
$PM_{2.5}$ (µg/m³)	65.27	135	94.38 ± 16.62	90.84
PM_{10} (µg/m³)	44	90.19	67.28 ± 11.74	68.55
AQI	65.91	135	99.05 ± 7.36	99.67

Daily values (24-h means) were derived from the Tehran municipal monitoring network

Table 2 displays the monthly average concentrations of air pollutants in conjunction with the mean daily COPD hospitalizations for each month, highlighting the months with the greatest hospitalization rates. This facilitates a comparison of air quality measures and hospitalization patterns over time. The data show that March 2023 saw the highest hospitalization rate, coinciding with a peak in $PM_{2.5}$ concentrations. Furthermore, for all months with increased hospitalization rates, $PM_{2.5}$ concentrations were significantly high. Based on our results, $PM_{2.5}$ has a leading effect, may even be the primary cause of its exacerbations.

Table 2: Monthly-mean COPD hospitalizations and concomitant mean air-pollutant concentrations in Tehran (8 months with the highest hospitalization counts)

Month (m-yy)	COPD hospitalizations mean	CO (ppm)	NO_2 (ppm)	O_3 (ppm)	$PM_{2.5}$ (µg/m³)	PM_{10} (µg/m³)	SO_2 (ppm)	AQI
March 2023	4.161	25.32	57.81	29.32	76.19	47.55	17.74	76.58
August 2023	3.852	26.90	71.42	84.87	84.58	70.84	17.26	99.90
December 2022	3.581	36.06	59.94	10.65	123.2	68.55	36.23	123.5
February 2024	3.579	28.24	63.48	19.21	89.90	53.34	22.21	89.90
September 2022	3.481	35.23	71.37	65.27	88.13	69.70	20.43	95.33
January 2023	3.444	35.19	64.58	12.52	135	75.71	33.52	137
April 2022	3.189	27.13	62.73	37.63	98.27	79.20	18.10	103.8
December 2023	3.129	40.06	82.87	11.90	117.3	75.19	30.19	117.5

Time series

Time series plots of multiple air pollutants (SO_2, PM_{10}, $PM_{2.5}$, NO_2, O_3, and CO) and AQI over a two-year period show distinct seasonal patterns and relationships among the pollutants (Fig. 2). Because of increased heating, industrial activity, and weather patterns that trap pollutants close to the ground, the majority of pollutants, including SO_2, PM_{10}, $PM_{2.5}$, NO_2, and CO, exhibit greater concentrations throughout the winter months (Dec to Feb). Conversely, ozone (O_3) has an inverse pattern, peaking during the summer months (Jun to Aug), which is characteristic due to its creation being facilitated by sunshine and elevated temperatures. The AQI strongly correlates with the trends of $PM_{2.5}$ and PM_{10}, suggesting that particulate matter significantly influences overall air quality in this location. Air quality is often worse in winter, underscoring the need for specific pollution management strategies during this season to safeguard public health.

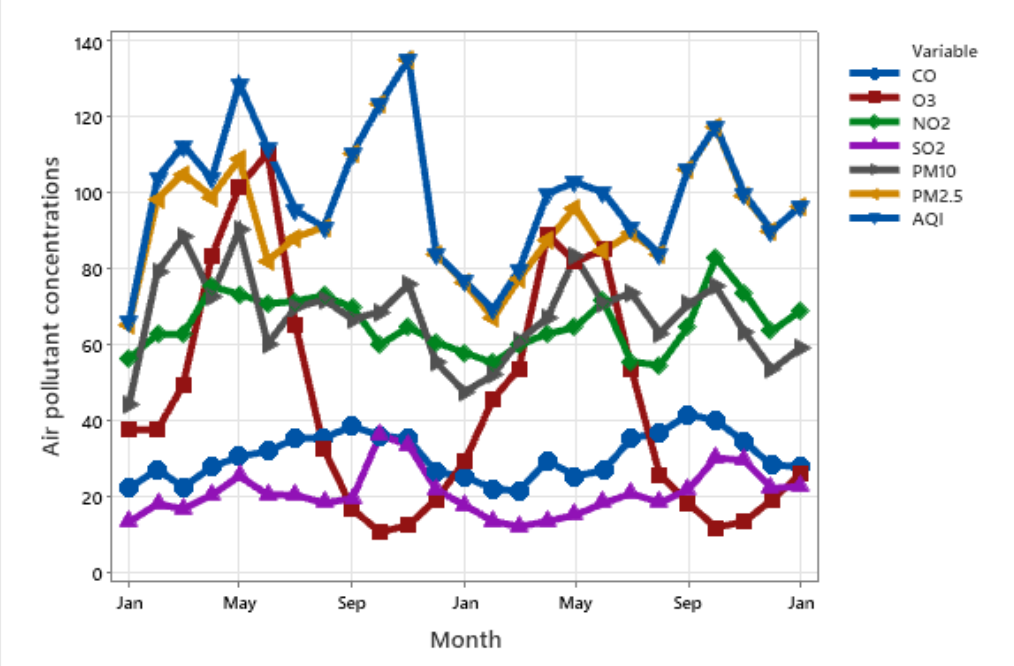

Fig. 2: Time series plots of various air pollutants (O3, NO2, NO, CO, SO2, PM10, $PM_{2.5}$) and the AQI (Air Quality Index) over a two-year period

Correlation analysis and PCA plot

Table 3 outlines the correlation matrix among air pollutants based on the Pearson coefficient. It was found that strong positive correlations among CO, $PM_{2.5}$, and SO_2 (Pearson's r>0.6). The findings reveal that the AQI has a correlation coefficient over 0.9 with $PM_{2.5}$ concentration, indicating a robust positive association. Moreover, the AQI exhibits robust associations (Pearson's r>0.6) with SO_2 and PM_{10}. A robust positive association is also shown between PM_{10} and $PM_{2.5}$. In contrast, O_3 has an inverse association with CO, SO_2, and $PM_{2.5}$. Fig. 3 shows the PCA plot of the air pollutant data. Principal component analysis (PCA) of the seven contaminants identifies two primary axes that account for the majority of variation and delineates three separate groups of pollutants. PC1 distinguishes dust and secondary particles (such as $PM_{2.5}$ and AQI) from combustion gases (SO_2 and CO), while PC2 emphasizes the distinct behavior of O_3, which exhibits an inverse correlation with winter traffic pollution. $PM_{2.5}$, PM_{10}, and NO_2 exhibit a tight clustering, suggesting shared origins and cumulative impacts on respiratory health, whereas O_3's unique distribution underscores the need for varied air quality control strategies.

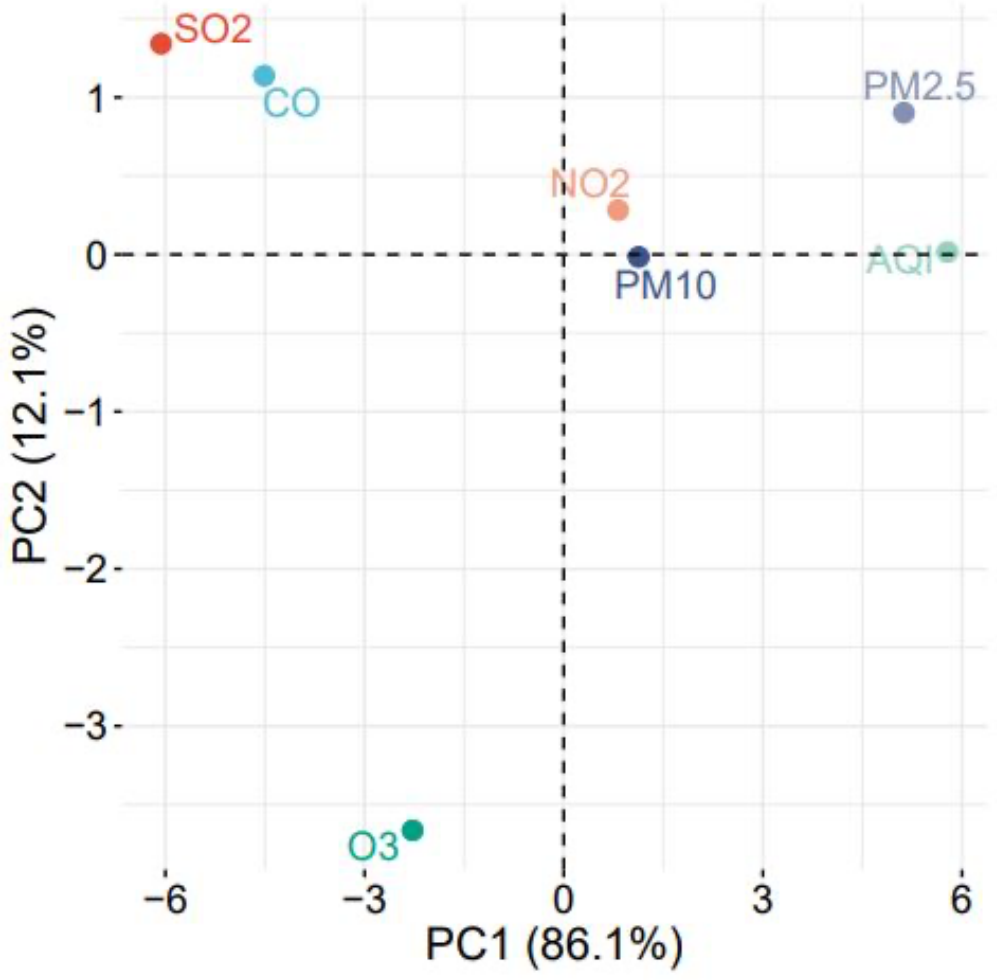

Fig. 3: Principal Component Analysis (PCA) plot of air pollutants

Table 3: The correlation analysis of Tehran's air pollutants from 2022 to 2024

Pearson correlation coefficient	CO	O3	NO2	SO2	PM10	PM2.5	AQI
CO	1.000						
O3	-0.334	1.000					
NO2	0.385	0.170	1.000				
SO2	0.603	-0.422*	0.378	1.000			
PM10	0.258	0.300	0.406*	.238	1.000		
PM2.5	0.582*	-0.299	0.433*	0.786*	0.639*	1.000	
AQI	0.492*	0.084	0.535*	0.686*	0.738*	0.905*	1.000

Values in bold with an asterisk are statistically significant at $P<0.05$ (two-tailed)

The relationship between pollutants and AQI

The monthly average graphs (Fig. 4) show that higher concentrations of CO, NO_2, SO_2, PM_{10}, and $PM_{2.5}$ are consistently linked to poorer air quality. As these pollutant levels rise, the Air Quality Index (AQI) increases, signaling more hazardous conditions for human health.

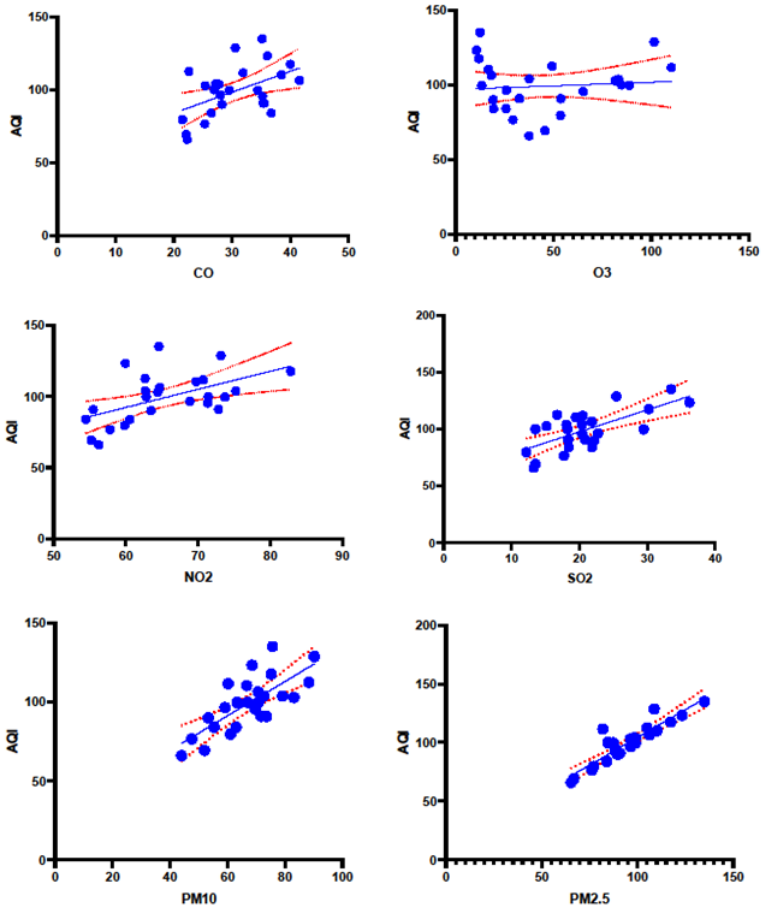

Fig. 4: Linear regression analysis between air pollution parameters ($PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, O_3) and the AQI

Association Between $PM_{2.5}$ Concentrations and COPD Hospitalizations

Fig. 5 shows the relationship between $PM_{2.5}$ concentrations (Y-axis, μg/m³) and hospital admissions (X-axis). The data spans from around 70 μg/m³ to 135 μg/m³ for $PM_{2.5}$, while admission counts vary from 1.5 to 4.5. The fitted regression line shows an increasing trend, indicating a positive correlation. However, the dispersion of data points around the line indicates variability, suggesting that other factors may possibly impact these variables. The figure illustrates that greater admission numbers are related with higher $PM_{2.5}$ levels.

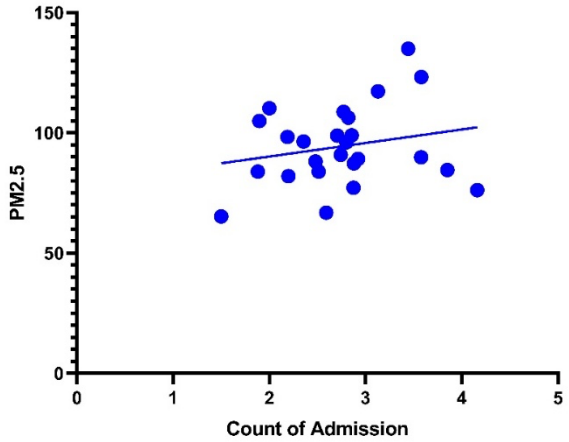

Fig. 5: Scatter-plot of monthly mean $PM_{2.5}$ versus mean daily COPD hospitalisations (March 2022–March 2024).

AirQPlus Results

We determined the long-term effects of exposure to particulate matter ($PM_{2.5}$ and PM_{10}), NO_2, and O_3 on COPD patients (Table 4). Long-term exposure to air pollutants was significantly associated with COPD morbidity and mortality in 2022–2023. Each 10 μg/m³ increase in $PM_{2.5}$ raised COPD hospitalization risk by 78% in 2022 and 74% in 2023, accounting for 44% of hospitalizations. A similar increase in PM_{10} was linked to 89% and 78% higher respiratory mortality in 2022 and 2023, responsible for 47% and 44% of deaths, respectively. NO_2 exposure increased COPD mortality by 41% and 37%, contributing to 29% and 27% of fatalities across the two years. In contrast, O_3 had a weak association, with mortality increasing by only 9.7% and 5.2% in 2022 and 2023. Overall, $PM_{2.5}$, PM_{10}, and NO_2 were major contributors to COPD-related health burdens, whereas O_3 exerted a minimal effect.

Table 4: Long-Term Air Pollution and Health Risk (2022-2023)

	2022			2023		
Pollutant	%RR	95%CI	%EAP	%RR	95%CI	%EAP
$PM_{2.5}$	1.78	1.59-2.02	43.8	1.74	1-56- 1.97	42.61
PM_{10}	1.89	1.38-2.65	47.06	1.78	1.35-2.44	44.05
NO_2	1.41	1.12-1.58	29.21	1.37	1.11-1.53	27.36
O_3	1.097	1-1.256	8.85	1.052	1-1.134	4.99

Relative Risk=RR; Estimated Attributable Proportion=EAP

Discussion

The use of fossil fuels, urbanization, and industrialization have all contributed to the intensification of pollution, disrupted atmospheric gases and exacerbated respiratory maladies. Nevertheless, the evidence regarding its involvement in COPD exacerbations is inconsistent: some studies indicate that there are no or pollutant-specific effects (22,23), while others observe a substantial increase in exacerbations and mortality (24,25).

In particular, our research evaluated the impact of air pollution on the hospitalization rate of patients with COPD. The levels of measured air pollutants ($PM_{2.5}$, PM_{10}, NO_2, SO_2, O_3, and AQI) were directly correlated with hospital admissions due to COPD exacerbations. Air pollution exposure was associated to a reduction in lung function and an increase in respiratory symptoms in COPD patients, leading to exacerbations and an elevated death rate (26). Our findings showed a strong association between AQI and $PM_{2.5}$, PM_{10}, NO_2, and SO_2. Moreover, our study shows a strong correlation between air pollution exposure and increased hospitalizations for COPD exacerbations, particularly with rising levels of $PM_{2.5}$. A number of international studies have been conducted in cities with elevated levels of air pollution, and these results are consistent with them. Short-term exposures to $PM_{2.5}$, PM_{10}, NO_2, SO_2, and CO were found to have adverse effects on COPD hospitalizations in a study conducted in Beijing, China (14). Sustained chronic exposure to $PM_{2.5}$ led to diminished lung function, emphysematous lesions, and airway inflammation Most significantly, long-term exposure to $PM_{2.5}$ exacerbated alterations mediated by cigarette smoking in COPD (27).

According to our analysis, individuals with COPD experience substantially deteriorated health outcomes as a result of long-term exposure to pollutants like $PM_{2.5}$ and PM_{10}, as determined by the AirQPlus software. In particular, the software predicts that the mortality rate from respiratory diseases among individuals aged 30 and older is elevated as a result of chronic exposure to these contaminants. Additionally, our results indicate that there are substantial correlations between hospitalizations related to COPD and exposure to $PM_{2.5}$. This implies that a considerable decrease in $PM_{2.5}$ levels could result in a substantial decrease in COPD hospital admissions, underscoring the potential public health benefits of enhanced air quality regulations. The use of fossil fuels and heating during colder months results in an increase in particle matter pollution ($PM_{2.5}$, PM10), which has a substantial impact on mortality. Our results indicate a robust correlation between elevated air pollution (SO2, $PM_{2.5}$, NO2, and AQI) and an increase in COPD hospitalizations, particularly during the months of Dec and Jan, when pollution reaches its highest level as a result of low temperatures and fossil fuel dependence. Furthermore, the year-round impact of air pollution on public health and COPD exacerbations is underscored by seasonal fluctuations, such as the elevated ozone levels observed in Jul–Aug.

Numerous studies have verified that COPD hospitalizations are exacerbated by elevated $PM_{2.5}$, PM10, NO2, and SO2 (28-30). Our research in Tehran, a city characterized by persistent air pollution, offers fresh data by analyzing the cumulative impacts of many contaminants over a two-year duration. Research indicates that $PM_{2.5}$, NO2 and PM10 have the strongest correlation with COPD hospitalizations. In order to reduce these risks, policy measures should prioritize the implementation of cleaner technologies, the expansion of sustainable transportation, the implementation of more stringent international air quality standards, and the enhancement of household energy efficiency. In order to mitigate PM-related COPD hospitalizations and protect public health, it is imperative to implement a proactive, collaborative strategy that involves governments, healthcare providers, and individuals.

Limitation

The ecological design of the study and the use of aggregated data restrict the ability to adjust for individual factors. Consequently, the results are indicative of the general correlations between air pollution and COPD hospitalizations, rather than

the specific hazards associated with individual patients. The results provide significant population-level evidence to inform public health and air quality policies, despite these limitations.

Conclusion

This study provides region-specific evidence of the health impacts of poor air quality by demonstrating a significant association between air pollution, particularly $PM_{2.5}$, PM_{10}, and NO_2, and COPD hospitalizations in Tehran. Improvements in public health and substantial decreases in hospital admissions may result from even modest reductions in pollutant levels. To overcome these obstacles, it is necessary to conduct ongoing research to inform effective interventions and coordinate efforts across the healthcare, community, and policy sectors.

Journalism Ethics considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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Conflict of interest

The authors declare that there is no conflict of interests.

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