Respiratory Health Conditions Associated with Long-Term Exposure to Air Pollution Across Different Age Groups: A Systematic Review

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Abstract: Air pollution has been regarded as a significant concern in environmental and human health. Various sources of air pollutants such as motor vehicles, coal combustion, and industrial processes are noted as the major generators of hazardous air pollutants including PM_{10}, $PM_{2.5}$, CO, CO_2, SO_2, and O_3. Human exposure to air pollution poses great risks of developing respiratory health conditions such as asthma, COPD, and pneumonia, which is becoming a serious concern especially to vulnerable age groups. This systematic review aims to underscore the existing respiratory health conditions associated with the exposure to long-term air pollution among different age groups. This review employed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Framework to establish a comprehensive collection and selection of relevant data aligned with this review's objectives. Findings have found nine (9) air pollutants from indoor and outdoor sources, PM_{10} being the contaminant having the highest concentration of 205.23 μg/m^3, which is somewhat regarded as relatively harmless among healthy people. Findings also highlight that the elderly are among the age groups that are at the highest risk to long-term exposure to air pollution. Additionally, findings indicate that PM and NO_2 are the top 2 air pollutants that show direct correlation between exposure and an increased risk of developing respiratory health conditions. Finally, results of this systematic review call for further development of risk assessment concerning exposure of the elderly to air pollution in order to provide a proper set of standards and guidelines.

Keywords: *Air Contaminants, Risk Assessment, Respiratory System, Human Exposure.*

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I. INTRODUCTION

Air pollution remains a significant public health concern worldwide, and the Philippines is no exception (Fong et al. 2020). Rapid urbanization, industrial expansion, and increasing vehicle emissions have contributed to worsening air quality, particularly in highly urbanized areas like Metro Manila (Andong and Sajor 2024). Many cities in the country exceed the World Health Organization's (WHO) air quality guidelines for pollutants such as particulate matter (PM), nitrogen oxides (NOx), and sulfur dioxide (SO_2), posing serious risks to respiratory health. This highlights the urgent need to examine the long-term effects of air pollution on Filipinos, particularly across different age groups.

Since the respiratory system is directly exposed to the air, it is especially vulnerable to the harmful effects of prolonged pollution exposure (World Health Organization 2021). While the short-term impacts of poor air quality have been extensively studied, the long-term consequences of continuous exposure require further investigation. Studies have consistently linked chronic exposure to pollutants like PM, nitrogen dioxide (NO_2), ozone (O_3), and sulfur dioxide (SO_2) to a higher risk of respiratory conditions, including asthma, chronic obstructive pulmonary disease (COPD), and lung infections (Pope & Dockery 2006). In the Philippines, these illnesses are among the most prevalent respiratory diseases, particularly affecting vulnerable groups (Burney et al. 2015).

Prolonged exposure to pollutants like $PM_{2.5}$ and PM_{10} has been associated with increased asthma attacks, especially in children (Keet et al. 2018). COPD, a progressive lung disease that causes breathing difficulties, has also been strongly linked to long-term exposure to air pollution, particularly among adults and the elderly (Hogg et al. 2017). Moreover, air pollution can weaken the immune system, making individuals more susceptible to respiratory infections like pneumonia, which can have severe consequences for young children and older adults (Schraufnagel et al. 2019).

However, not all age groups are affected in the same way. Children are more vulnerable due to their developing lungs, while older adults face higher risks due to the natural decline in lung function (Landrigan et al. 2018). Additionally, the sources of air pollution—such as vehicle emissions, industrial processes, and household pollutants—impact different age groups in varying ways (Manisalidis et al. 2020). In the Philippines, major pollution sources like jeepney emissions and industrial activities near residential areas play a significant role in deteriorating air quality (Boquet, 2017).

Despite existing research, a comprehensive analysis of specific air pollutants, their sources, and their effects on different age groups remains limited (Lelieveld et al. 2018). This knowledge gap hinders the creation of targeted public health policies, particularly in the Philippine context. Furthermore, the biological mechanisms that contribute to age-related differences in susceptibility to pollution-related respiratory diseases are not yet fully understood, and the localized impact of different pollution sources requires further study (Wu at al. 2023).

To address these gaps, this systematic review aims to: (1) identify and classify the specific air pollutants studied in relation to long-term exposure and respiratory health; (2) analyze the sources of air pollution and their contributions to health outcomes; (3) assess the prevalence of respiratory symptoms, infections, and diseases across different age groups; and (4) explore the underlying mechanisms that make certain age groups more susceptible to pollution-related respiratory conditions. By bridging these gaps, this review seeks to contribute to more effective public health strategies aimed at protecting vulnerable populations in the Philippines.

➢ *Objectives of the Study*

- To identify and categorize the specific air pollutants investigated in studies examining long-term exposure and respiratory health.
- To identify the various sources of air pollution and how the contribution of different pollution sources affects respiratory health outcomes.
- To explore the prevalence of respiratory symptoms/infections/diseases in different age groups.
- To investigate the possible medical interventions for respiratory-related symptoms/diseases following long-term exposure to air pollution.

II. METHODOLOGY

This systematic review adhered to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure a rigorous and transparent selection process. This review investigated the effects of long-term air pollution exposure on respiratory health across different age groups, using publications from 2015 to 2025.

➢ *Data Sources*

Relevant publications were identified through a systematic search of Google Scholar, ResearchGate, Elsevier, Springer, and Academia.edu, in accordance with the PRISMA guidelines.

➢ *Literature Search*

A systematic literature search was conducted across five electronic databases: Google Scholar, ResearchGate, Elsevier, Springer, and Academia.edu. To ensure comprehensive coverage, three sets of search terms were combined using Boolean operators (AND, OR) within each database's search interface. The first set of terms focused on air pollutants, including variations of "particulate matter," "ozone," "nitrogen dioxide," and "sulfur dioxide" in combination with "air." The second set explored risk assessment related to air pollution, using terms such as "air pollution health effects," "air pollution exposure risk," and "adverse impacts of air pollution." The third set of terms investigated the link between air pollution and the respiratory system, including combinations of "respiratory disease," "lung health," and "air pollution." Finally, a fourth set of terms addressed age-related exposure, using combinations of "air pollution exposure" with "children," "adults," and "elderly."

The search was limited to peer-reviewed research articles and reviews published in English between 2015 and 2025. Initial screening involved examining titles, authors, publication dates, and journal names to identify and remove duplicate entries. Subsequently, abstracts of potentially relevant articles were screened, followed by full-text review of those meeting the inclusion criteria for the systematic review.

➢ *Inclusion and Exclusion Criteria*

The included articles were categorized according to several key criteria: (1) primary focus on the effects of long-term air pollution exposure on respiratory health across different age groups; (2) identification of specific air pollutants associated with adverse respiratory health outcomes; (3) investigation of air pollution exposure in relation to individual air contaminants; (4) direct assessment of air pollution-related health risks in various age cohorts; (5) publication date between 2015 and 2025; (6) publication type (original research article or review); (7) availability of full text; and (8) language of publication (English or English translation available).

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Studies were excluded based on the following criteria: (1) publication type (case series, case report, or narrative review); (2) absence of relevant outcome parameters or research data; (3) lack of full-text availability; and (4) unavailability of English text or translation.

➢ *Search Results*

The initial search across Google Scholar, ResearchGate, Elsevier, Springer, and Academia.edu yielded 46 potentially relevant publications. These results were filtered to include only research articles and reviews published in English between 2015 and 2025, resulting in the exclusion of 15 publications. The remaining 31 records underwent a two-stage screening process.

First, titles and abstracts were assessed for relevance, leading to the removal of 21 records. The eligibility of the remaining 10 publications was then evaluated, with full-text access being a key criterion. Ultimately, four studies were included in the qualitative analysis, while six studies met the criteria for inclusion in the quantitative synthesis. The study selection process is summarized in the PRISMA flow diagram (See Figure 1).

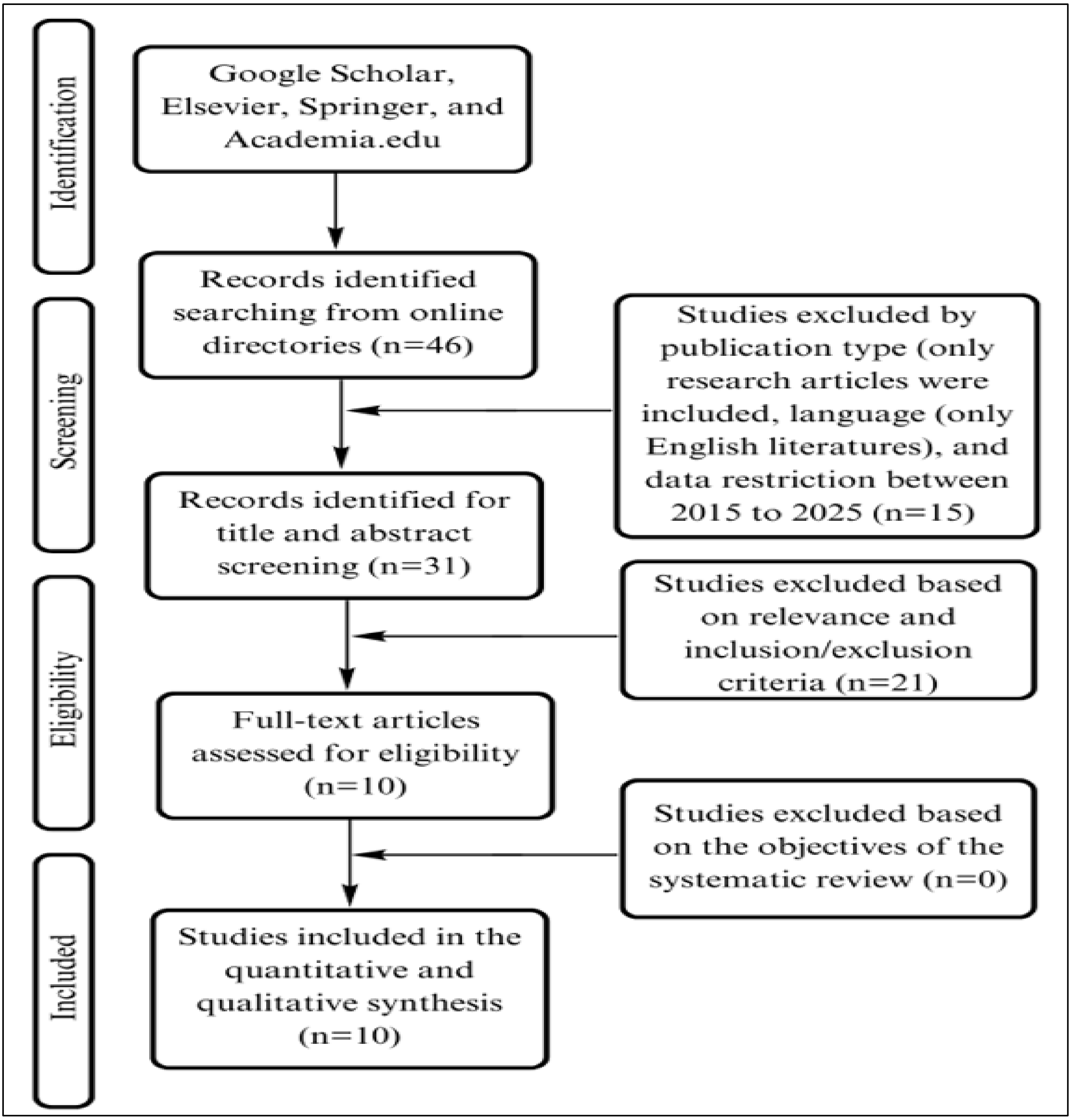

Fig 1 PRISMA Stages of Study Selection of Related Studies Flow Diagram

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➢ *Data Extraction*

Ten studies, selected from an initial pool of 45 publications based on pre-defined eligibility criteria, form the basis of this systematic review. This review encompasses international research on the topic. Data and information pertinent to the research question were extracted from these studies.

The extracted data encompassed several key areas: (1) specific air pollutants implicated in adverse respiratory health effects; (2) primary sources of air pollution and their relative contribution to respiratory health outcomes; (3) both acute and chronic respiratory health effects linked to long-term air pollution exposure; and (4) the impact of air pollution exposure on the health risks of different age groups.

➢ *Statistical Analysis*

Following the tabulation and qualitative assessment of the selected studies, the literature underwent further evaluation to determine its suitability for both quantitative and qualitative analyses. Studies addressing the air pollutants associated with adverse respiratory health effects, age-related health risks, and the acute and chronic respiratory effects of long-term air pollution exposure were prioritized to ensure alignment with the review's objectives.

III. RESULTS AND DISCUSSION

➢ *Scientific Articles and Journals Related to Respiratory Health Effects Associated with Long-term Exposure to Air Pollution*

The collection of the top 10 studies related to the focus and objectives of this systematic review can be seen in Appendix A. These studies have undergone meticulous screening—applying the PRISMA Framework (See Figure 1)—in order to effectively determine the necessary information aligned with the key objectives of this review.

These relevant studies have enabled the researchers to determine and quantify the existing prevalence of various air pollutants, which constitute persisting air pollution, and their effect following the long-term exposure of various age groups (See Figure 2 and Table 3) in different regions.

➢ *Overview of Long-Term Exposure to Air Pollution*

According to the World Health Organization (WHO), air pollution has been long considered a major environmental and health problem affecting everyone, low-, middle-, and even high-income countries. The Environmental Protection Agency has set standards for air quality called the 'National Ambient Air Quality Standards (NAAQS)' in compliance with the U.S. Clean Air Act. This set of standards established common air pollutants: particulate matter (or sometimes called particle pollution, ground-level ozone (O_3), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and lead (Pb). Moreover, there are various compounds that are considered hazardous air pollutants (HAPs) and these are: benzene, perchloroethylene, methylene chloride, dioxins, asbestos, toluene, and metals such as cadmium, mercury, chromium, and lead compounds.

Xiao et al. (2015) have noted three top sources of air pollutants, and these are motor vehicles, waste burning, and industrial facilities, which significantly contribute to the formation of other secondary pollutants, such as ground-level ozone, affecting the public health and putting people at great risk. Moreover, sources of air pollutants can be further categorized such as indoor sources including people's movement, cooking, cleaning, and the use of different products (Rivas, I. et al. 2019).

In Asia, where air pollution is relatively high, cases of long-term exposure among various age groups are relatively common and thus can be easily linked to various health conditions such as asthma, COPD, pneumonia, and worse, mortality. Additionally, the effects of long-term air pollution vary depending on several factors including age of the exposed groups, regional variations, and current and past health conditions.

➢ *Ambient Air Contaminants*

Air pollutants are particles interfering with the ambient quality of the air, this may include toxic substances and gases discharged in large quantities from various sources such as mobile vehicles, factories, and industrial combustions (McCormack 2008; Lee 2021). Various compounds have been regarded as air contaminants according to the World Health Organization (WHO) and Environmental Protection Agency (EPA), these are: Particulate matter ($PM_{2.5}$ and PM_{10}, Nitrogen oxides (NOx), Sulfur oxides (SOx), Carbon monoxide (CO), Carbon dioxide (CO_2), Ozone (O_3), and Lead (Pb).

Particulate matter refers to the wide variation of small substances that are suspended in the air, either solid, liquid, or a mix of both (Yang et al. 2022; Gokul et al. 2023), and they may be further classified based on their chemical composition and sizes (Tositti 2018; Zhang et al. 2021; Gokul et al. 2023). PM are classified into four types: PM_{10} (coarse particulate matter) (≤10 µm), $PM_{2.5}$ (fine particulate matter) (≤2.5 µm), and PM0.1 (ultrafine particulate matter) (≤0.1 µm) (Schraufnagel 2020). Additionally, $PM_{0.3}$ particles with a diameter of <0.3 µm are classified as quasi-ultrafine particles. The majority of PM particles are formed in the environment through chemical reactions between contaminants (Kirichenko et al. 2020; Gokul et al. 2023).

Nitrogen oxides are a combination of nitrogen oxide (NO) and nitrogen dioxide. They are among the most significant species involved in the air pollution problem. Nitrogen oxides actively contribute to the chemical events that cause the creation of tropospheric ozone (O3) (Allegrini 2023).

Primary gaseous SO_2 and secondary particulate sulfate are the main forms of sulfur oxides in the air. SO_2 is produced when sulfur-containing fossil fuels (mostly coal or oil) are burned, as well as during metal smelting and other industrial operations. The highest observed SO_2 concentrations are typically found near major industrial sites that lack contemporary emission controls, such as older coal-fired power stations (Thurston 2017).

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Carbon monoxide (CO) is a colorless gas that is undetectable by the human olfactory system (Binions and Naik 2013). Conversely, as a result of incomplete combustion of hydrocarbon compounds, CO is regarded as a major component of air pollution related to vehicle and tobacco smoke emissions (US Environmental Protection Agency 2012, Vrijheid et al. 2012; Levy 2015).

Carbon dioxide is the most common greenhouse gas and accounts for about 76% of greenhouse gases (Fletcher and Smith 2022) and it is a critical compound in photosynthesis for plant growth and subsequently for the existence of animal life (Tedesco 2022). On the contrary, Carbon dioxide (CO_2) emissions have been considered one of the main sources of air pollution, leading to a serious worry due to their climatic impacts as greenhouse gases (GHG) (Hadipoor et al. 2021).

Ozone (O_3) is a gas comprised of three oxygen atoms that exists at atmospheric pressures and temperatures. The stratosphere, a layer of the atmosphere about 10-50 km above the Earth's surface, contains the majority of ozone (about 90%) (Wuebbles 2013). Additionally, Surface ozone is mainly contributed by photochemical reactions of volatile organic compounds (VOCs) with nitrogen oxides (NOx) (Wang et al. 2017; Li et al. 2022).

Air pollution has a severe influence on human health, increasing the burden of disease and the need for healthcare services (Lee 2021). Additionally, according to a Global Burden of Disease estimate, air pollution is the fourth leading cause of disability-adjusted life years (DALYs) and mortality, accounting for over 200 million DALYs and 6.67 million deaths in 2019 (Abbafati et al. 2019).

Table 1 The Recorded Air Pollutants, their Categories, and Concentrations from the Top 10 Articles. Bold Values Exceeded the National Ambient Air Quality Standards.

Study No.	Air Pollutants	Category	Concentration/ Level	Sampling Method	Reference
1	$PM_{2.5}$	Primary/Secondary	DNA	PM2.5 air quality sensors	Seposo, X. et al. (2021)
2	$PM_{2.5}$	Primary/Secondary	**99.5 µg/m^3**	Filter-based sampling over 24 hours using gravimetric analysis	Chen, Z. et al. (2019)
	PM_{10}	Primary/Secondary	**205.23 µg/m^3**		
	NO_2	Primary	**53.1 µg/m^3**		
	SO_2	Primary	58.33 µg/m^3		
	CO	Primary	1.5 µg/m^3		
	O_3	Secondary	**105.23 µg/m^3**		
3	$PM_{2.5}$	Primary/Secondary	20.1 µg/^{3}	Spatiotemporal model and Chemical transport model	Marchetti, P. et al. (2023)
	PM_{10}	Primary/Secondary	28.7 µg/m^3		
	NO_2	Primary	27.2 µg/m^3		
	O_3	Secondary	**70.8 µg/m^3**		
4	$PM_{2.5}$	Primary/Secondary	**119.5 µg/m^3**	DNA	Mendes, A. et al. (2015)
	PM_{10}	Primary/Secondary	132.5 µg/m^3		
	TVOC	Primary	127.5 µg/m^3		
	Formaldehyde	Primary/Secondary	80.5 µg/m^3		
	CO	Primary	131 mg/m^3		
	CO2	Primary	131 mg/m^3		
	Bacteria	Primary	139 CFU/m^3		
	Fungi	Primary	125 CFU/m^3		
5	$PM_{2.5}$	Primary/Secondary	14.28 µg/m^3	Land Use Regression (LUR) model	Fuertes, E. et al. (2015)
	PM_{10}	Primary/Secondary	22.32 µg/m^3		
	NO_2	Primary	21.86 µg/m^3		
	O_3	Secondary	**44.08 µg/m^3**		
6	PM_{10}	Primary/Secondary	#27.5 µg/m^3	Ogawa passive sampler	Dimakopoulou, K. et al. (2022)
			#26.9 µg/m3^3		
	O_3	Secondary	#67.9 µg/m		
			#58.6 µg/m^3		
7	$PM_{2.5}$	Secondary	**75.97 µg/m^3**	Meteorological monitoring	Wright, N. et al. (2023)
	PM_{10}	Secondary	84.9 µg/m^3		
	NO_2	Primary	**68.67 µg/m^3**		
	SO_2	Primary	30.4 µg/m^3		
	O_3	Secondary	**97.6 µg/m^3**		
	CO	Primary	0.49 mg/m^3		
8	$PM_{2.5}$	Primary/Secondary	4.5 µg*m^{-3}	Satellite-based Land Use Regression (LUR) model	Salimi, F. et al. (2018)
	NO_2	Primary	17.5 µg*m^{-3}		
9	$PM_{2.5}$	Primary/Secondary	27.4 µg/m3	Lascar EasyLog USB	Anastasaki et al. (2021)
	CO	Primary	12.3 ppm		
10	$PM_{2.5}$	Primary/Secondary	&34.96 µg/m^3		Wei, S. et al. (2023)

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			[&]54.81 μg/m³	Two-stage machine learning model and Tree-based gap-filling method	

- *Legends:*

✓ *[#]Locational Variation*
✓ *[&]Temporal Variation*
✓ *DNA = Data Not Available*

➢ *Quantitative Results*

- *Concentrations of Air Pollutants*

In this systematic review, air pollutants were collected in different studies to determine the prevalence and their health impacts on the respiratory system in various age groups. $PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, O_3, TVOC, CO_2, Formaldehyde, Bacteria, and Fungi are the recorded air pollutants extracted upon reviewing relevant articles for this study (See Table 1). Bold values on the table represent that concentrations have exceeded the National Ambient Air Quality Standards, which is used as a basis for further assessing the relationship of these air pollutants to the respiratory-related health conditions of the exposed groups.

Study 1 emphasized $PM_{2.5}$ as the top concern in the area of the study, however, the authors did not reveal the quantitative value of the concentration of the said air pollutant, nonetheless, it showed a relevant impact on the respiratory health of the sample. Study 2 revealed six (6) air pollutants: $PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, and O_3, with the values of 99.5 μg/m³, 205.23 μg/m³, 53.1 μg/m³, 58.33 μg/m³, 1.5 μg/m³, and 105.23 μg/m³, respectively. Concentrations of $PM_{2.5}$, PM_{10}, NO_2, and O_3 were notably high, exceeding the air quality standards set by NAAQS. Study 3 recorded four (4) air pollutants: $PM_{2.5}$, PM_{10}, NO_2, and O_3, with the values of 20.1 μg/m³, 28.7 μg/m³, 27.2 μg/m³, and 70.8 μg/m³, respectively—Ozone (O_3) being the only air pollutant exceeded the NAAQS. Study 4 recorded a total of eight (8) air pollutants: $PM_{2.5}$, PM_{10}, TVOC, Formaldehyde, CO, CO_2, Bacteria, and Fungi, with the values of 119.5 μg/m³, 132.5 μg/m³, 127.5 μg/m³, 80.5 μg/m³, 131 mg/m³, 131 mg/m³, 139 CFU/m³, and 125 CFU/m³, respectively. As you may have noticed, this study has included air pollutants other than those typical air pollutants aforementioned. Formaldehyde, Bacteria, and Fungi are just some of the possible air pollutants that may exist in an indoor setup—in this particular study by Mendes et al (2015), indoor air pollutants are the concern. Study 5 recorded four (4) air pollutants: $PM_{2.5}$, PM_{10}, NO_2, and O_3, with the values of 14.28 μg/m³, 22.32 μg/m³, 21.86 μg/m³, and 44.08 μg/m³, respectively—Ozone (O_3) being the only air pollutant exceeded the NAAQS.

Study 6 recorded only two (2) air pollutants: PM_{10} and O_3, conducted in two locational variations, with the values of 27.5 μg/m³ and 26.9 μg/m³ for PM_{10} and 67.9 μg/m³, 58.6 μg/m³ for O_3. In this case, the second locational variation for ozone exhibited a higher value than the air quality standards set by NAAQS. Study 7 recorded six (6) air pollutants: $PM_{2.5}$, PM_{10}, NO_2, SO_2, O_3, and CO, with the values of 75.97 μg/m³, 84.9 μg/m³, 68.67 μg/m³, 30.4 μg/m³, 97.6 μg/m³, and 0.49 mg/m³, respectively—$PM_{2.5}$, NO_2, and O_3 have exceeded the NAAQS. Study 8 recorded two (2) air pollutants: $PM_{2.5}$ and NO_2 with the values of 4.5 μg*m^{-3} and 17.5 μg*m^{-3}, respectively. Study 9 recorded two (2)

Air pollutants: $PM_{2.5}$ and CO with the values of 27.4 μg/m³ and 12.3 ppm, respectively. Finally, study 10 recorded $PM_{2.5}$ air pollutants with the two (2) temporal variation values of 34.96 μg/m³ and 54.81 μg/m³, the second value being highest and exceeding the NAAQS.

These findings highlight the variations of air pollutants and their perspective concentrations in various locations and times, which may have played a role in the differences in levels. Evaluating these values is crucial in determining the possible health impacts on humans, especially in respiratory and pulmonary health.

- *Air Pollutant with the Highest Recorded Concentration*

A study conducted by Chen et al. (2019) revealed a surprising result with the air pollutant, particularly PM_{10}, recorded with a concentration of 205.23 μg/m³ (See Table 1), almost twice the value of the air quality standard set by NAAQS. Chen et al. (2019) noted that the high levels of PM_{10} may be due to the existence of various factories located near the study area—a primary school in Jinan, China.

Particulate Matter (PM) is generally produced from natural and anthropogenic activities or processes, these particles may vary in their physical and chemical characteristics, which may directly imply their possible effects on human health, particularly in respiratory (Chlebowska-Styś, A. et al. 2017). Additionally, according to Tornevi et al. (2022), exposure to PM_{10} with high values—even exceeding the standard values—generally does not pose any major negative effect to human health. However, particular groups with a weakened immune system or the elderly are considered vulnerable (Chen, T. et al. 2021).

- *Prevalence of Cases Associated with Long-Term Exposure to Air Pollution*

Figure 2 highlights the prevalence of the exposure of different age groups to long-term air pollution. The collected data revealed that seniors (people aged 61 to 80 years old) are the group that is most exposed to long-term air pollution—a total of six (6) studies collected from the PRISMA Framework. A study conducted by Salimi, F. et al. (2018) showed that participants aged 71 to 84 years old had the highest cases of hospitalization, however, it is not ascertained that the age and number of hospitalizations are strongly associated with exposure to long-term air pollution. Similarly, Mendes et al. (2016) found that the risks of allergic rhinitis are highest among older people who are exposed to an indoor environment contaminated with cigarettes and PM_{10}. Similar studies also have found that the elderly are among the most exposed group to long-term outdoor air pollution, constituting great risks of cardiopulmonary and

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respiratory diseases. Future studies are suggested to follow up with the elderly population in order to investigate the long-term effects of exposure to air pollution (Simoni, M. et al. 2015).

Second to the elderly are young adults (aged 21 to 40 years old) and middle adulthood (aged 41 to 60). This may indicate that people in these age groups often make use of their time making ends meet—going to work, attending institutions, or going for leisure—resulting in long-term exposure to outdoor air pollution. Third to the most exposed groups are the youth (aged 0 to 20 years old)—with four (4) studies constituting the prevalence—who are mostly exposed to outdoor and indoor air pollution. With this concerning data related to exposure of children and youths, relevant studies showed great risks of respiratory-related conditions occurring in this particular age group such as pneumonia, asthma, and decreased lung function.

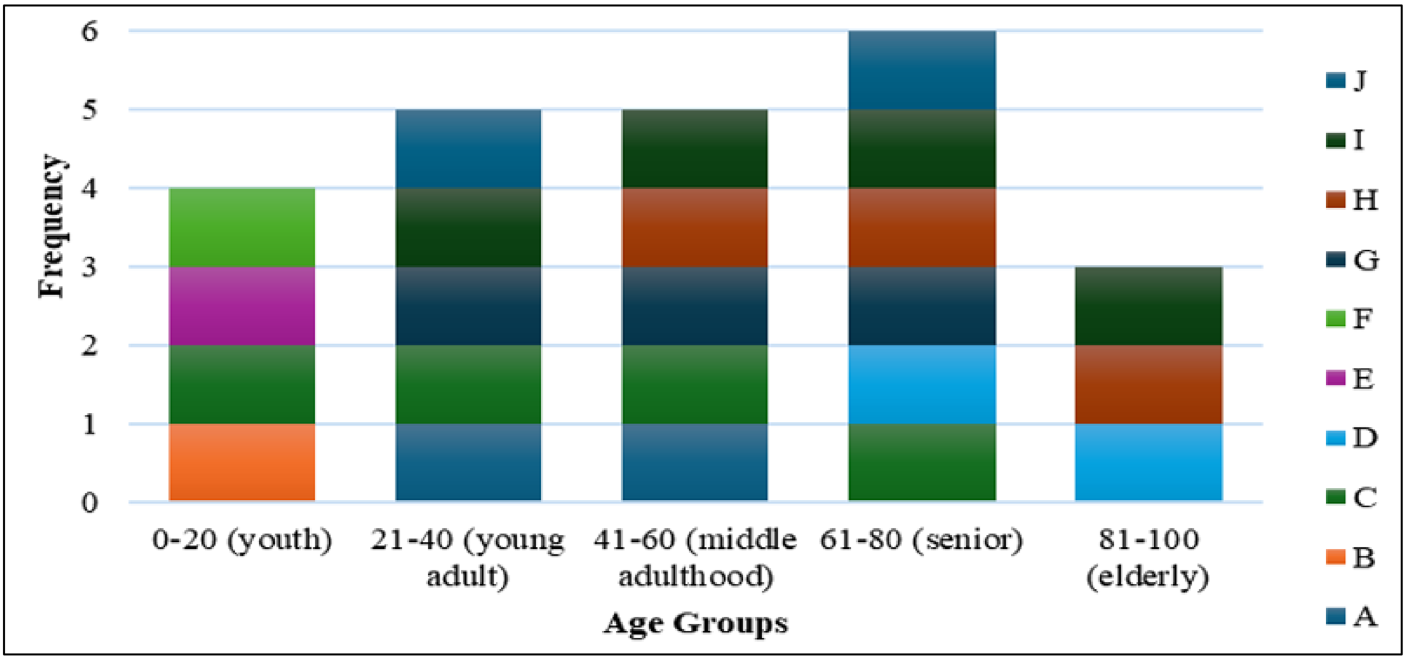

Fig 2 Prevalence of Exposed Age Groups to Long-Term Air Pollution

Table 2 Air Pollutants, their Sources, and Regions where the Study was Conducted.

Study No.	Air Pollutants	Sources	Country/Region	Reference
1	$PM_{2.5}$	Outdoor: Motor vehicles, Dust	Metro Manila, Philippines	Seposo, X. et al. (2021)
2	$PM_{2.5}$ PM_{10} NO_2 SO_2 CO O_3	Outdoor: Motor vehicles, Industrial emissions, Combustion processes, and Dust	Jinan, China	Chen, Z. et al. (2019)
3	$PM_{2.5}$ PM_{10} NO_2 O_3	Outdoor: Motor vehicles, Industrial emissions, and Combustion processes	*Italy	Marchetti, P. et al. (2023)
4	$PM_{2.5}$ PM_{10} TVOC Formaldehyde CO CO2 Bacteria Fungi	Indoor: Fuel combustion and Household materials	Porto, Portugal	Mendes, A. et al. (2015)
5	$PM_{2.5}$ PM_{10} NO, O_3	Outdoor and Indoor: Motor vehicles and Secondhand smoke	*Germany	Fuertes, E. et al. (2015)

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6	$PM1_0$ O_3	Outdoor and Indoor: Motor vehicles and Household materials	Athens and Thessaloniki, Greece	Dimakopoulou, K. et al. (2022)
7	$PM_{2.5}$ PM_{10} NO_2 SO_2 O_3 CO	Outdoor: Motor vehicles and Combustion processes	Suzhou, China	Wright, N. et al. (2023)
8	$PM_{2.5}$ NO_2	DNA	Sydney, Australia	Salimi, F. et al. (2018)
9	$PM_{2.5}$ CO	Outdoor: Motor vehicles, Industrial emissions, Combustion processes, and Dust	Crete, Greece	Anastasaki et al. (2021)
10	$PM_{2.5}$	Indoor: Secondhand smoke, and Household materials	*China	Wei, S. et al. (2023)

- *Legends:*

✓ **Multiple Region/State*
✓ *DNA = Data Not Available*

➢ *Qualitative Results*

- *Sources of Air Pollutants*

Vehicular emissions are a primary contributor to air pollution, particularly in densely populated urban areas like Metro Manila, according to Seposo et al. (2021). This is attributed to the sheer volume of vehicles on the roads, often compounded by outdated engine technologies, poor fuel quality, and inadequate emission standards. The constant congestion leads to a build-up of exhaust fumes, rich in particulate matter (PM), nitrogen dioxide (NO_2), and other harmful pollutants. These pollutants contribute to respiratory problems, cardiovascular diseases, and other health issues. Similarly, studies in Jinan (Chen, Z. et al. 2019) and Suzhou (Wright, N. et al. 2023) highlight the impact of rapid urbanization and increased vehicle ownership on air quality.

Industrial activities are another major source, particularly in regions with significant manufacturing sectors. In Suzhou (Wright, N. et al. 2023), industrial emissions are a key source of PM, NO_2, SO_2, and O_3. This is due to the release of pollutants from factories, power plants, and other industrial facilities, often involving the combustion of fossil fuels and the release of chemical byproducts.

The specific pollutants emitted depend on the type of industrial activity, with heavy industries like steel and cement production often releasing significant amounts of particulate matter and sulfur dioxide. This is consistent with findings in Germany (Fuertes, E. et al. 2015), where industrial processes contribute significantly to air pollution. Indoor air pollution remains a concern, especially in regions with high reliance on solid fuels for household energy. In Porto (Mendes, A. et al. 2015), indoor sources like tobacco smoke and building materials contribute to poor air quality. Similarly, in China (Wei, S. et al. 2023), the burning of coal and biomass for heating and cooking releases substantial pollutants, posing serious health risks to residents, particularly in rural areas with limited access to cleaner energy sources.

Geographic and climatic factors can exacerbate air pollution. In Crete (Anastasaki et al. 2021), dust and wildfires contribute to PM levels, influenced by the dry climate and seasonal winds. The arid landscape and strong winds can lead to the suspension of dust particles in the air, while wildfires release significant amounts of smoke and particulate matter. In Sydney (Salimi, F. et al. 2018), temperature inversions, where a layer of warm air traps cooler air near the ground, can prevent pollutants from dispersing, leading to higher concentrations of NO_2 and other air pollutants. This phenomenon is often observed in cities located in valleys or coastal areas, where geographic features can influence air circulation patterns.

The gathered data demonstrates a clear link between the sources of air pollution and the specific characteristics of each region. Urbanization, industrialization, household energy practices, and geographic factors all contribute to the air pollution profile of an area.

- *Respiratory-related Conditions Associated with Air Pollution*

Several respiratory-related conditions associated with air pollution were recorded from the articles reviewed. Particulate matter ($PM_{2.5}$ and PM_{10}) is strongly associated with reported cases of wheezing, cough, sputum, asthma, tracheitis, bronchitis, and allergic rhinitis. This correlation is supported by studies like Chen et al. (2019), which found a high prevalence of respiratory symptoms in children exposed to $PM_{2.5}$. Furthermore, research by Marchetti et al. (2023) directly links PM exposure to impaired lung function.

Nitrogen dioxide (NO_2) exposure, while not directly linked to specific illnesses, is associated with broader systemic health impacts. Studies like Salimi et al. (2018) and Wright et al. (2023) have linked NO_2 to cardiovascular and respiratory diseases, and even mental health concerns. This suggests that NO_2 may contribute to the overall health burden, even if specific NO_2-related illnesses are not explicitly mentioned. The presence of other pollutants like SO_2, O_3, and CO further strengthens the connection between air pollution and respiratory health risks. These pollutants are known to irritate the respiratory system and contribute to the development of respiratory illnesses.

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The data demonstrates a direct correlation between exposure to air pollutants, particularly PM and NO_2, and an increased risk of respiratory illnesses and potentially broader systemic health issues. This highlights the urgent need for air quality management strategies to mitigate these health risks.

Table 3 Age Groups of the Participants and the Recorded Respiratory-Related Symptoms, Infections, and Diseases.

Study No.	N	Age Group	Respiratory-related symptoms/infections/diseases	Reference
1	52 traffic enforcers	40 to 50 years old	Chronic obstructive pulmonary disease (COPD)	Seposo, X. et al. (2021)
2	2532 children	7 to 16 years old	Recurrent respiratory function, pneumonia, asthma, tracheitis, bronchitis, allergic rhinitis	Chen, Z. et al. (2019)
3	1731 participants	18 to 65 years old	Rhinitis, asthma, chronic bronchitis, COPD	Marchetti, P. et al. (2023)
4	668 participants	65 years old and older	Wheezing, cough, sputum. asthma, allergic rhinitis	Mendes, A. et al. (2015)
5	2266 participants	15 years old	Asthma	Fuertes, E. et al. (2015)
6	186 participating students	10 - 11 years old	Asthma, wheezing, Dyspnea, Fever, Cough, Stuffy nose,	Dimakopoulou, K. et al. (2022)
7	50,407 participants	30 - 79 years old	COPD, Pneumonia, ischaemic stroke	Wright, N. et al. (2023)
8	100,084 participants	45 years old and older	Asthma, pneumonia, COPD	Salimi, F. et al. (2018)
9	32 households	35 to 95 years old	Fatigue, headache, irritated eyes, nausea, dizziness, phlegm, wheezing, and breathlessness	Anastasaki et al. (2021)
10	10,142 participants	40 - 70 years old	Allergic nasal symptoms, Allergic eye symptoms, Wheezing, Dyspnea	Wei, S. et al. (2023)

- *Age Group with the Highest Risk to Long-Term Exposure to Air Pollution*

Based on the gathered data, a focused analysis reveals that individuals spanning a broad age range, from children aged 7 to 16 years old to adults aged 65 years old and older, exhibit heightened susceptibility to respiratory-related symptoms and diseases linked to long-term air pollution exposure. Specifically, children aged 7 to 16 years old, according to Chen et al. (2019) are documented to experience recurrent respiratory dysfunction, pneumonia, asthma, tracheitis, bronchitis, and allergic rhinitis. Developing respiratory systems in younger individuals are particularly vulnerable to the detrimental effects of air pollutants.

Moreover, adults aged 65 and older, according to Mendes et al. (2015), reported cases of wheezing, cough, sputum, asthma, and allergic rhinitis, indicating a persistent vulnerability to respiratory issues in older age groups. Aging populations often experience a decline in respiratory function, making them more susceptible to the adverse impacts of air pollution. While other age groups, according to Seposo et al. (2021) and Marchetti et al. (2023), such as traffic enforcers aged 40-50 and participants aged 18-65 respectively, also report respiratory symptoms, the data highlights the extended vulnerability of both younger and older individuals across a wider spectrum of respiratory ailments.

Therefore, the evidence implies that children and older adults represent age groups with a demonstrably higher risk of developing long-term respiratory complications stemming from chronic exposure to air pollution. This emphasizes the critical need for targeted interventions and public health strategies aimed at mitigating air pollution exposure specifically for these vulnerable populations.

- *Health Risks Following Exposure to Air Pollution*

While respiratory illnesses are frequently associated with air pollution, a deeper analysis of the data reveals a concerning range of systemic health risks that extend far beyond the respiratory system. This emphasizes the pervasive impact of air pollution on human health, affecting various organs and systems within the body. One major concern is the link between air pollution and cardiovascular diseases. Studies have shown that fine particulate matter ($PM_{2.5}$) and nitrogen dioxide (NO_2) can significantly increase the risk of heart attacks, strokes, and other cardiovascular complications. $PM_{2.5}$, in particular, is small enough to penetrate deep into the lungs and enter the bloodstream, triggering inflammation, oxidative stress, and endothelial dysfunction (Rajagopalan et al. 2018). These processes can damage blood vessels and contribute to the development of atherosclerosis, hypertension, and other cardiovascular problems. Research by Singh et al. (2023) in Sydney, for example, found a direct correlation between NO_2 exposure and increased hospital admissions for cardiovascular events.

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Furthermore, emerging evidence suggests that air pollution can also impact neurological health. Studies have linked exposure to air pollution with an increased risk of cognitive decline, dementia, and neurodegenerative diseases like Alzheimer's disease (Chen et al. 2017). Air pollutants can potentially cross the blood-brain barrier, leading to neuroinflammation, oxidative stress, and neuronal damage. This can disrupt normal brain function and contribute to cognitive impairment and neurodegenerative processes. Additionally, air pollution has been found to have adverse effects on pregnancy outcomes. Exposure to air pollution during pregnancy has been associated with preterm birth, low birth weight, and preeclampsia (Ha et al. 2014). Air pollutants can potentially affect fetal development by impairing placental function, causing oxidative stress, and triggering inflammation, all of which can disrupt the delicate balance of pregnancy and lead to complications.

Moreover, air pollution has been linked to an increased risk of metabolic disorders like diabetes and obesity. Studies suggest that air pollution can disrupt glucose metabolism, promote insulin resistance, and contribute to chronic inflammation, which are key factors in the development of these metabolic diseases (Wang et al. 2014). This highlights the complex interplay between air pollution and metabolic health. Furthermore, long-term exposure to air pollution has been associated with an increased risk of certain types of cancer, including lung cancer, bladder cancer, and leukemia (Hamra et al. 2014). Air pollutants can contain carcinogenic substances that can damage DNA and initiate the development of cancer. This underscores the serious long-term health consequences of air pollution.

The data paints a clear picture of the wide-ranging systemic health risks associated with air pollution exposure. Beyond respiratory illnesses, air pollution can contribute to cardiovascular diseases, neurological effects, adverse pregnancy outcomes, metabolic disorders, and cancer.

- *Medical Interventions for Respiratory-Related Conditions*

In the research study conducted by Rajper et al. (2018), Chinese students who were the respondents for this study claimed that they were aware of the effects of air pollution on health, which led them to adapt preventive measures such as wearing respiratory masks and drinking enough water to avoid dehydration. Face mask usage to protect health and reduce inhalation of air pollutants has become increasingly acceptable and common worldwide, especially in Asia. While these masks are meant to reduce the amount of harmful air pollutants breathed in, their effectiveness varies according to the kind of mask and filter used, the types of pollutants in the air, and how the mask is being worn or used (Laumbach et al. 2015). Another medical intervention is to treat and manage respiratory conditions. Individuals with chronic respiratory illnesses like asthma and COPD are advised to limit their exposure to air pollutants, due to their increased susceptibility to the adverse effects of air pollution. Both COPD management consensus recommendations and the Global Initiative for Asthma (GINA) strategy advocate for reducing exposure to ambient and household air pollution. In a study by Péter et al. (2015), to improve diet and use supplements with antioxidants or anti-inflammatory agents is another way to manage respiratory-related illnesses associated with air pollution. Moreover, consuming a well-balanced diet, rich in antioxidants, protein, fiber, and polyunsaturated fatty acids, is linked to a decreased risk of chronic lung conditions that are worsened by exposure to air pollution.

IV. CONCLUSIONS

This systematic review has synthesized current research on the long-term effects of air pollution on respiratory health across different age groups, revealing significant insights into the extent and nature of this pervasive public health issue, particularly relevant to regions like the Philippines. The analysis of ten studies, conducted between 2015 and 2025, underscores the critical role of specific air pollutants, notably $PM_{2.5}$, PM_{10}, NO_2, and O_3, in contributing to a spectrum of respiratory conditions, including asthma, COPD, and increased susceptibility to infections.

The findings demonstrate a clear correlation between elevated concentrations of these pollutants and adverse respiratory health outcomes, with several studies reporting levels exceeding national ambient air quality standards. Notably, PM_{10} was identified as having the highest recorded concentration in one study, highlighting the impact of industrial activities and urbanization on air quality. Furthermore, the review revealed a disproportionate impact on vulnerable populations, with the elderly and children exhibiting the highest risk of developing respiratory complications from chronic exposure.

Beyond respiratory illnesses, the review highlighted the systemic health risks associated with air pollution, including cardiovascular diseases, neurological effects, adverse pregnancy outcomes, metabolic disorders, and cancer. This underscores the need for a holistic approach to addressing air pollution, recognizing its multifaceted impact on human health.

The review also explored the various sources of air pollution, emphasizing vehicular emissions, industrial activities, and indoor sources as primary contributors. Geographic and climatic factors were also identified as exacerbating factors, influencing the dispersion and concentration of pollutants.

Medical interventions, such as the use of respiratory masks, dietary modifications, and the management of chronic respiratory conditions, were discussed as potential strategies to mitigate the adverse effects of air pollution. However, the review emphasizes that these interventions are secondary to the primary need for robust public health policies aimed at reducing air pollution at its source.

In conclusion, this systematic review reinforces the urgent need for comprehensive strategies to address air pollution and protect vulnerable populations. Future research should focus on further elucidating the biological mechanisms underlying age-related differences in

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susceptibility, exploring the localized impact of specific pollution sources, and evaluating the effectiveness of targeted interventions. By bridging these knowledge gaps, more effective public health policies and interventions can be developed to safeguard respiratory health and improve overall well-being in the face of increasing air pollution challenges.

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APPENDICES

➢ *Appendix A. Top 10 Studies Used in this Systematic Review*

No.	Title	Year	Author/s
1	Ambient air quality and the risk for Chronic Obstructive Pulmonary Disease among Metro Manila Development Authority traffic enforcers in Metro Manila: An exploratory study	2021	Seposo, X. et al.
2	The Association Between High Ambient Air Pollution Exposure and Respiratory Health of Young Children: A Cross Sectional Study in Jinan, China	2019	Chen, Z. et al.
3	Long-term Residential Exposure to Air Pollution and Risk of Chronic Respiratory Diseases in Italy: The BIGEPI Study	2023	Marchetti, P. et al.
4	The Impact of Indoor Air Quality and Contaminants on Respiratory Health of Older People Living in Long-term Care Residences in Porto	2015	Mendes, A. et al.
5	Long-term Air Pollution Exposure and Lung Function in 15 Year-old Adolescents Living in an Urban and Rural Area in Germany: The GINIplus and LISAplus Cohorts	2015	Fuertes, E. et al.
6	Long-term Exposure to Ozone and Children's Respiratory Health: Results From the RESPOZE Study	2022	Dimakopoulou, K. et al.
7	Long-term Ambient Air Pollution Exposure and Cardio-respiratory Disease in China: Findings from A Prospective Cohort Study	2023	Wright, N. et al.
8	Long-term Exposure to Low Concentrations of Air Pollutants and Hospitalisation for Respiratory Diseases: A Prospective Cohort Study in Australia	2018	Salimi, F. et al.
9	Household Air Pollution and Respiratory Health in Rural Crete, Greece: A Cross-Sectional FRESH AIR Study	2021	Anastasaki et al.
10	Ambient Fine Particulate Matter and Allergic Symptoms in the Middle-aged and Elderly Population: Results from the PIFCOPD Study	2023	Wei, S. et al.