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ELUCIDATING THE MECHANISMS UNDERLYING THE ASSOCIATION BETWEEN AIR POLLUTION AND RESPIRATORY DISEASE: A REVIEW OF THE EVIDENCE

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Abstract

As a result of the numerous respiratory ailments the air pollution is now a serious public health issue on a global scale. This article explores how air pollution affects respiratory health, focusing on the impacts of pollutants including nitrogen oxides, sulfur dioxide, carbon monoxide, particulate matter, and ozone. The article also includes epidemiological information, illness induction strategies, vulnerable populations, and potential mitigation strategies. Indoor and outdoor air pollution is a major risk factor for respiratory diseases. Asthma is the second most common cause of respiratory avoidable deaths and disease burden linked to exposure to air pollution, after Chronic Obstructive Pulmonary Disease. Asthma significantly affects morbidity and quality of life, in contrast to COPD, which has a high burden of morbidity, including quality of life, and early mortality. Particulate matter, ozone, and nitrogen oxides are recognized to contribute to respiratory disorders. Additional details regarding the burden of disease brought on by air pollution can be found here. All of the sources of air pollutants and how they are responsible for respiratory illnesses will be covered in this overview. The purpose of this study is to present a summary of recent findings about the connection between respiratory conditions and air pollution.

INTRODUCTION

The airways are the primary entry point for air contaminants into the body. Some of these pollutants can cause acute reactions, such as inflammation and oxidative stress, which can exacerbate pre-existing illnesses like asthma and COPD or cause respiratory symptoms. These illnesses are also known to be caused by prolonged revelation to air pollution (Kim *et al.*, 2018). Long-term exposure to pollutants like PM 2.5 (fine particulate matter with a diameter of 2.5 micrometers or less), PM10 (coarse particulate matter with a diameter of 10 micrometers or less), and NO_2 has been shown to significantly increase the risk of developing COPD, especially in individuals with a high genetic predisposition and unhealthy lifestyles. All originates from natural resources such as pollen and wildfires, industrial processes, construction dust, and automobile emissions. Heart problems, respiratory illnesses, and other health issues might be exacerbated by high concentrations of these pollutants. Furthermore, these pollutants enhance the risk of asthma, especially in children, where a 3% increase in asthma incidence is correlated with a 1 $\mu g/m^3$ increase in PM 2.5 concentration (Kelly, 2014).The health of the world is seriously threatened by air pollution. WHO (2020a, b) estimates that air pollution causes around 8 million premature deaths globally, mainly from respiratory and cardiovascular conditions, with 4.2 million coming from outdoor sources and 3.8 million from domestic

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pollution. Currently, 90% of people on the planet reside in places with air quality that is below WHO standards. It is commonly known that exposure to air pollution can cause and exacerbate a number of respiratory conditions. On the contrary, epidemiological studies suggest that changes in the respiratory microbiota may worsen respiratory conditions like bronchitis, asthma, chronic obstructive pulmonary disease (COPD), and lung cancer. The microbiota, a significant regulator of respiratory health, is influenced by air pollution and aids in preserving airway homeostasis. Nevertheless, little is known about how air pollution affects respiratory microbial ecosystems and how it contributes to the development of disease (Xue *et al.*, 2020).

Broader Categories of Air Pollution

Indoor and outdoor air pollution are two more general groups that encompass a variety of air pollution kinds that can lead to respiratory illnesses.

Indoor Air Pollution

Indoor air quality is the condition of the air inside or around buildings and structures, with an emphasis on the comfort and well-being of occupants. The risk of health problems can be reduced by controlling and reducing prevalent indoor pollutants. It may take years for the consequences of indoor air pollution to become apparent, or they may appear soon after exposure (Bruce *et al.*, 2006).

Immediate Effects of Indoor Air Pollution

Short-term, easily treatable symptoms including headaches, weariness, dizziness, and irritation can be brought on by indoor pollution exposure. Additionally, pollutants can cause or exacerbate asthma. Age, health, and exposure levels are some of the variables that affect sensitivity. Monitoring when and where symptoms appear aids in identifying possible indoor air problems because they might mimic colds. Uneven humidity and insufficient ventilation can worsen these effects (Apte & Salvi, 2016).

Long-Term Indoor Air Pollution's Effects

Improving indoor air quality is important even if no symptoms see right away because indoor pollutants can cause health problems years after exposure or after repeated, long-term engagement. These health problems can include serious states such as cancer, heart disease, and respiratory diseases, which can be acute or even fatal (Pérez-Padilla *et al.*, 2010). More research is required to ascertain the consequences of short-term high exposure vs usual household pollution levels, as individual responses differ. Although indoor pollutants are recognized to have negative health effects, it is still unclear what exact exposure amounts and times are required to produce particular illnesses (Cheek *et al.*, 2021).

Key Causes of Indoor Air Pollution

Problems with indoor air quality are mostly caused by sources that emit toxic gases or particles; high temperatures and humidity can exacerbate some pollutants; and inadequate ventilation can exacerbate pollution levels by not bringing in fresh air to dilute emissions and remove indoor contaminants (Rivas *et al.*, 2019).

Common Sources of Indoor Pollutants

There are several sources of indoor pollution in a building. Gas stoves and fireplaces are examples of combustion appliances that emit dangerous emissions. VOCs can be released by building materials and furnishings, such as cabinets and furniture made of pressed wood. Indoor pollution can also be caused by humidifiers and heating, airing, and air cooling (HVAC) systems. Furthermore, too much moisture can cause mold to grow, and chemicals and radon from the outdoors can enter the house. Indoor pollution is made worse by new flooring and interior finishes, deteriorating asbestos insulation, and home goods including cleaning supplies and personal hygiene products. (Nasikas *et al.*, 2024). The degree of pollution is determined by the source's age, maintenance, toxicity, and emission levels. While some things, such as air fresheners and furnishings, emit pollutants continuously, other actions, like smoking, cleaning, or renovating, emit pollutants intermittently. Dangerously high quantities of pollutants can be produced by malfunctioning or poorly ventilated machines. Even after their source has been eliminated, some

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contaminants can persist in the atmosphere regularly (Salthammer, 2020).

Global Impact of Indoor Air Pollution

Indoor air pollution is a major cause of premature mortality and a major environmental danger, particularly in low-income nations where access to clean cooking fuels is limited. It is a significant risk factor for several severe conditions, including diabetes, heart disease, and pneumonia, stroke, and lung cancer. Indoor air pollution is one of the leading causes of death worldwide, according to the Global Burden of Disease report. In less developed places, where the impacts are more severe, it is one of the most dangerous health risks. Global data show its widespread influence, and phenomena unique to some countries can be further investigated. (González- Martín *et al.*, 2021).

Health Risks of Household Air Pollution (HAP)

Burning biomass fuels exposes over three billion people globally to household air pollution (HAP). Every year, this exposure causes around 2.9 million fatalities and has serious negative effects on social, economic, and health outcomes, particularly in nations with poor and medium incomes (Vardoulakis *et al.*, 2020). Acute infections, TB, lung, pneumoconiosis, asthma, and chronic obstructive pulmonary disease (COPD), head, and neck malignancies have all been related to HAP, according to research. Although, no clear- cut link between the two has been found. The results of many researches are incompatible because they do not report for outside variables like outdoor air pollution and tobacco smoke. Systematic diagnostic techniques and enhanced environmental monitoring are needed to differentiate the effects of HAP from those of other contaminants. Healthcare professionals should take into account early examinations for populations that may be more susceptible to respiratory illnesses due to prior or current HAP exposure (Simkovich *et al.*, 2019).

Outdoor Air Pollution

Ambient air is the term used to describe outdoor air. The usual sources of outdoor air pollution are industrial processes, solid fuel combustion, and pollutants released by motor vehicle combustion. A crucial environmental health concern which can affect people of all income levels globally is outdoor air pollution. Because of being revealed to fine aerosols, that can cause cancer, respiratory diseases, and cardiovascular diseases, it was linked with over 4.2 million unreasonable deaths per year in 2019 (Adamkiewicz *et al.*, 2020). According to the World Health Organization, ischemic heart disorder and stroke accounted for 68% of these deaths, while acute lower pulmonary infections and chronic hindering pulmonary disease (COPD) alone accounted for 14%. Lung cancer was accountable for 4% of death. Low- and middle- income nations, especially those in the WHO Western Pacific and South-East Asia regions, carry a disproportionately acute burden from outdoor air pollution, accounting for 89% of these premature deaths. These findings show that air pollution significantly impairs cardiovascular health and overall mortality (Spezzano, 2021).

Outdoor Air Pollutants and Sources

Common outdoor air pollutants include sulfur dioxide, nitrogen dioxide, particulate matter, ozone, and hazardous air pollutants (Verhoeven *et al.*, 2021). Transportation, domestic sources, business and industrial smoke, and electric utilities are the primary contributors of outdoor air pollution (Irawan *et al.*, 2021).

Major Air Pollutants and Their Sources Ammonia (NH_3)

Ammonia is a colorless gas that smells strongly of something. Agricultural practices, such as the manufacturing of fertilizer and the manure of livestock, are its main sources, while cleaning supplies and cigarette smoke can expose people indoors. Even small levels of ammonia can irritate the eyes, nose, throat, and respiratory system since it is corrosive. High concentrations of ammonia can be toxic. Ecosystems on land and in water are eutrophied and acidified as a result of it. Ammonia also affects air quality by forming fine particulate matter (PM2.5) through reactions with other air pollutants (Odubo & Kosoe, 2024).

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Carbon Monoxide (CO)

Cars and combustion engines are the main sources of carbon monoxide, a poisonous, colorless, odorless, and tasteless gas. While power plants, biomass burning, forest fires, and the wood industry are examples of outside sources, indoor sources include boilers, fireplaces, ovens, cooker hoods, tobacco smoke, and propane heaters. By entering the bloodstream through inhalation, carbon monoxide reduces the quantity of oxygen that reaches tissues and organs. High doses can be fatal, and its harmful effects are especially dangerous for young children, the elderly, and people with heart or respiratory conditions (Sonwani & Saxena, 2016).

Nitric Oxide (NO)

Vehicles and power plants are the main sources of nitric oxide, commonly referred to as nitrogen monoxide, a poisonous, colorless gas that is created when coal and petroleum are burned. It mixes with atmospheric water vapor to create acidic chemicals that harm ecosystems, infrastructure, and vegetation. Moreover, it releases ground-level ozone (O3), a vital air pollutant, through interactivity with volatile organic molecules (Ayala *et al.*, 2012).

Nitrogen Dioxide (NO_2)

When nitric oxide (NO) is oxidized during combustion in diesel engines and when coal, oil, gas, wood, and waste are burned, nitrogen dioxide is created. It raises the risk of stroke and has a detrimental effect on respiratory health in both people and animals. Acid rain is created when it combines with water vapor, just like nitrogen monoxide does. Furthermore, nitrogen dioxide forms lower level ozone and forms fine particulate matter (PM 2.5) when it reacts to other pollutants like ammonia (Aggarwal & Jain, 2015).

Ozone (O_3)

Under intense sunlight and ultraviolet light, nitrogen oxides, carbon monoxide, and volatile organic molecules undergo photochemical reactions to produce ozone, a pale blue gas with a pungent stench. Electric motors in devices like copiers and laser printers may be the source of it indoors. Ozone is thought to contribute to respiratory illnesses, decreased lung function, and early mortality in addition to its probable carcinogenic effects. Additionally, the health dangers, it damages plants, which lessen crop production and erodes forests. It also contributes remarkably to smog and speeds up the decay of materials like rubber, paints, dyes, and fabrics etc. (Maji *et al.*, 2023).

Particulate Matter (PM)

The combination of solid and liquid materials forms the particulate matter. While secondary PM is created by chemical reactions involving pollutants including sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and ammonia (NH_3), primary PM is directly sourced from sources such as power plants, automobiles, construction sites, and indoor stoves. Asthma, bronchitis, and emphysema are among the respiratory and cardiovascular conditions that are associated with particulate matter exposure. Particle size determines the health impact; PM10 contains particles less than 10 microns, PM2.5 contains fine material less than 2.5 microns, and PM 0.1 contains ultrafine particles even smaller. Because they can thoroughly enter the bloodstream, lungs, and even the brain, smaller particles present greater health hazards (Daellenbach *et al.*, 2020).

Sulfur Dioxide (SO2)

The main sources of SO2, a poisonous gas with a strong, pungent smell, are the combustion and refinement of fossil fuels and metal ores, as well as emergence from shipping and other forms of transportation. Both humans and animals may develop lung illnesses as a result of this respiratory irritant. It causes acid rain when combined with water, which damages plants, erodes structures, and adds to the acidity of soil and water. Furthermore, sulfur dioxide affects air quality by reacting with other atmospheric substances like ammonia to create fine particulate matter (PM 2.5) (McLinden *et al.*, 2016).

Gaseous Organic Compounds

(GOCs) are a broad category of carbon-based compounds that include organic acids,

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alcohols, aldehydes, and hydrocarbons. While interior concentrations are higher because of things including furniture, plastics, carpets, wallpaper, cleaning products, solvents, and tobacco smoke, outdoor sources include emissions from incomplete combustion and industrial operations. VOC exposure presents serious health risks the reason is that people pass most of their time inside, particularly following construction or renovations. High doses can have harmful, cancer-causing, and mutagenic consequences, whereas low levels might be innocuous. The symptoms, which are frequently associated with Sick Building Syndrome, include headaches, exhaustion, disturbed sleep, respiratory problems, and decreased productivity. Furthermore, reactive VOCs exacerbate air pollution by contributing to very small dust particles (PM 2.5) and low-level ozone (Liang *et al.*, 2023).

Respiratory Diseases Associated with Air Pollution

Asthma air pollution increase inflammation and airway hyper responsiveness which in turn triggers asthma flare-up. Chronic Obstructive Pulmonary Disease (COPD) and a loss in lung functions are caused by prolonged exposure to pollutants. Lung cancer occur as toxic air pollutants and fine soot raise the danger of lung cancer. Respiratory illness because pollutants weaken the immune system, people are more vulnerable to illness like bronchitis and pneumonia (Tran *et al.*, 2023)

Mechanisms of Air Pollution-Induced Respiratory Damage

There are two sources of air pollution: primary pollutants released straight from exhaust pipes and stacks, and secondary pollutants created when sunlight, moisture, or both are present in the environment (Kim *et al.*, 2018). Puffiness and free radicle damage: Reactive free radicles (ROS) produced by pollutants cause tissue damage and inflammation. Airway Remodeling: Prolonged exposure causes the airways to shift structurally, which exacerbates respiratory disorders. Immune System Alterations: Air pollution can impair lung health by suppressing or exaggerating immune responses. The following are some of the ways that air pollution cause harm: airway inflammation brought on with the production of reactive free radicles, which induces oxidative damage. Impacting immunological processes, including the onset of allergies and the body's reaction to infections. Studies on controlled human and animal exposure have shown that particles placed in the respiratory tract in sufficient quantities can produce puffiness. The particle dose and makeup determine how much inflammation there is in the lungs (Shahriyari *et al.*, 2022).

Vulnerable Populations

Including both acute infectious processes and chronic disorders, lung diseases rank among the main reason of mortality for children below the age of five. Notably, asthma is the most prevalent chronic illness, affecting 14% of children worldwide and becoming more common. Certain populations and life stages may be more susceptible to the poor health effects of wildfire smoke, and those consequences may be more severe. We call these groups "at-risk populations." The phrase "sensitive groups" is used in the Air Quality Index. Epidemiologic studies that look at exposure to fine particle pollution in urban environments have found key risk factors that determine whether a group or person is more susceptible to health consequences from wildfire smoke (Viegi *et al.*, 2020). Children are especially vulnerable to pollution-related harm due to their developing lungs and higher inhalation rates. Elderly As people age, their lung function declines, making them more susceptible to air pollution. People with, those who have already heart risk, COPD, or asthma are more likely to experience negative side effects. Low-Income Communities, greater exposure because of their closeness to industrial areas and restricted access to healthcare (Labaki & Han, 2020).

Air Pollution and the COVID-19 Pandemic

The Relationship linking Air Pollution and COVID-19 Severity Prolonged subjection to air pollution has been appear to have a profound effect on the seriousness of COVID-19 cases. People who resided in regions with elevated amounts of pollutants, including sulfur dioxide (SO2), nitrogen dioxide (NO2), and particulate matter (PM 2.5), had a higher

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chance of dying from COVID-19 infections and becoming seriously ill, according to studies. The primary factors include (Aveyard *et al.*, 2021). Prolonged exposure to air pollution raises the threat of respiratory conditions like asthma and chronic obstructive pulmonary disease (COPD), causes inflammation and impairs lung function. The severity of COVID-19 is increased by several underlying disorders like weakened immune response, increased viral transmission, greater hospitalization as information from a number of nation's shows that areas with greater pollution levels saw higher COVID-19 hospitalization and mortality rates (Berman & Ebisu, 2020).

Lessons Learned: Air Quality Improvement during Lockdowns

One unexpected effect of the COVID-19 pandemic was the notable improvement in air quality that lockdown protocols brought about. Because there was less industrial activity, transportation, and human movement, pollution levels sharply declined globally. Key conclusions from this period include (Semczuk- Kaczmarek *et al.*, 2022).

1. Pollutant Decrease: Significant drops in air pollutants were detect by cities worldwide. For example, lower vehicle emissions caused nitrogen dioxide levels in large cities to drop by about 30- 60%.
2. Health Benefits: Respiratory illnesses and associated hospitalizations decreased consequently, the brief development in ambient air quality, underscoring the direct benefits of lowering pollution.
3. Sustainable Practices: The epidemic showed that legislative changes can drastically reduce emissions. Examples of these include allowing employees to work remotely, boosting the use of renewable energy sources, and enhancing public transportation.
4. Implications for Policy: Governments and environmental organizations now possess hard data regarding how human activity affects air quality. The argument for stronger emissions regulations and sustainable urban development is supported by this data (Travaglio *et al.*, 2021)

Moving Forward

The urgency with which air pollution must be addressed as a public health issue was highlighted by the COVID-19 epidemic. Strengthening air quality monitoring systems should be the main goal of future initiatives like stricter industrial emissions laws are being put into place, promote environmentally friendly energy options and encouraging sustainable urban transportation. Societies can reduce future health risks related to air pollution and improve community health resilience by incorporating all these lessons into long- term plans (Ali & Islam, 2020).

Genetic Susceptibility to Air Pollution

According to recent research, a person's genetic makeup significantly influences how they react to air pollution. Differences in susceptibility to pollution- related disorders might result from specific genetic variants that affect the body's capacity to detoxify contaminants. Important conclusions include (Johansson *et al.*, 2019). Genetic Variants and Inflammation: Some people have genetic diseases that increase their susceptibility to inflammation in response to pollution, which raises their risk of cardiovascular and respiratory illnesses. Metabolic Differences: The body's ability to digest and get rid of dangerous substances might be affected by genetic variances in the enzymes that detoxify air contaminants. Ethnic and Population-Based Vulnerabilities: Research indicates that some groups may be more susceptible to health problems associated with pollution because of common genetic characteristics. Both genetic and socioenvironmental variables are responsible for this. Implications for Public Health: Knowledge of genetic vulnerability can be used to customize public health treatments and policies, such as individualized medical plans to lessen the impacts of air pollution and targeted health advisories for high-risk groups (Cui *et al.*, 2023).

Mitigation Strategies and Public Health Interventions

Regulatory Measures and Policy Implementation

Governments should enforce strict emission limits and air quality standards in order to

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reduce pollution. Lawmakers ought to mandate that businesses reduce emissions and use more environmentally friendly industrial techniques. Fuel and vehicle emission restrictions can help minimize pollution associated with transportation. Stricter penalties and incentives for businesses to adopt sustainable practices can boost compliance (Sofia *et al.*, 2020).

Technological Innovations for Cleaner Environments

Non-renewable energy sources can be out back by the use of renewable energy sources like hydroelectric, solar, and wind. Expanded charging infrastructure, tax breaks, and subsidies should all be used to inspire the application of electric cars (EVs). Air purification technology and industrial filtration systems can reduce the amount of dangerous pollutants released. IoT and AI-powered smart monitoring systems can be used to track pollution levels and optimize remedies (Jonidi Jafari *et al.*, 2021).

Promoting Understanding and Collaboration

Public understanding and collaboration ought to aware people about the dangers of air pollution to their health as well as strategies for lowering exposure. Promoting individual behaviors like riding a bike, carpooling, and using less energy will help lower pollution levels generally. Sustainability initiatives can be included into companies and schools to encourage environmentally responsible practices. Private organizations and advocacy groups can support the cause of more robust environmental regulations and corporate accountability (Coelho *et al.*, 2021).

Urban Planning and Infrastructure Development

Air quality can be enhanced and pollutants can be absorbed by increasing the amount of urban green space, such as parks and roadways lined with trees. Reliance on private vehicles can be decreased by better public transportation systems. Walkable neighborhoods, eco-friendly structures, and effective waste management should all be incorporated into sustainable city development. Cities can restrict high-pollution cars and promote cleaner transportation options by implementing low-emission zones (Wang *et al.*, 2024).

CONCLUSION

Many people's COVID-19 has gotten worse due to air pollution, which is strongly linked to respiratory illnesses. In addition to harming lung health, prolonged subjection to pollutants such as PM 2.5, NO2, and SO2 exacerbates pre-existing diseases and raises the chance of infection. Nonetheless, the improvements in air quality during pandemic lockdowns demonstrated that lowering pollution can have positive health effects right away. Additionally, genetic variables make certain persons more susceptible to air pollution, thus public health strategies should take these variances into account. Governments and communities must enact stronger laws, make investments in clean technologies, raise public awareness, and enhance urban planning in order to solve this problem. In addition to lowering respiratory illnesses, these actions will improve the environment for coming generations and make it more sustainable. Since there is strong evidence that air pollution causes respiratory illnesses, immediate action to cut emissions and lower health hazards is required. In order to tackle this worldwide health catastrophe, policy measures, technology solutions, and individual awareness are essential. To safeguard public health, future studies should concentrate on long-term impacts and creative intervention techniques.

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