Impact of Pollution on Human Respiratory and Intestinal Health

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Abstract

This chapter examines the significant impacts of pollution on intestinal and respiratory health, emphasizing the complex relationships between these systems. We start by classifying several forms of pollution, along with the particular pollutants, including heavy metals, nitrogen dioxide, and particle matter. As global pollution levels rise, the health risks posed by environmental contaminants become more critical. The detrimental effects of air pollution on respiratory health, particularly with specific attention to respiratory infections, lung cancer, asthma, and chronic obstructive pulmonary disease (COPD). We discuss how pollution damages gut health and causes gastrointestinal infections and inflammatory bowel disease. Crucially, we highlighted the link between intestine and respiratory health, showing how contaminants can alter immune responses and gut microbiota. Understanding these intricate connections, we highlighted all-encompassing initiatives that reduce pollution and safeguard public health are desperately needed, and a holistic approach to environmental health that acknowledges the interdependence of our body's systems and overall is encouraged.

Keywords: Pollution, Respiratory health, Intestinal health, GUT-micro biota, GUT lung axis, Pollutants, Immune response

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Introduction

Pollution

Waste from human activity is called pollution (Fuller et al., 2022). When the air, water, soil, and living things are altered, it is called pollution (Mohammed Al-Dulaimi & Hassan Al-Taai, 2021). The release of materials into the environment with effects is known as pollution (Manisalidis et al., 2020). Introducing materials through processes that threaten health and the ecosystem (Mir et al., 2023).

Types of Pollution

Air pollution (polycyclic aromatic hydrocarbons and nitrogen dioxide) causes around 6.4 million annual deaths due to industry and urbanization. Human health is primarily impacted by air pollution through inhalation, which causes oxidative stress, aggravates asthma, inflammatory reactions in the respiratory tract, and immune system malfunction (Landrigan, 2017). The overuse of pesticides and fertilizers, which leak into water sources and cause eutrophication and damage to aquatic ecosystems, results from agricultural water Pollution, a global issue (Zahoor & Mushtaq, 2023). The main source of agricultural water pollution is the runoff of artificial fertilizers contaminating surface and groundwater the overuse of pesticides increases heavy metals in soil and poses dangers like neurotoxicity and cancer (Rad et al., 2022). Water pollution is a serious public health concern that disproportionately affects children in low-income nations, skin conditions, cancers, cardiovascular problems, and other health issues (Lin et al., 2022). Soil Pollution results from decreased soil quality, contaminants including chromium, mercury, lead, and arsenic, industrialization, and agricultural practices impact soil productivity and health (Lull et al., 2022). Roughly 25 million agricultural workers are poisoned by pesticides annually, soil provides about 95% of the food consumed worldwide. Epidemiological research links cardiovascular disorders to heavy metals elevated blood cadmium levels increase stroke risk by 2.39-fold (Münzel et al., 2023). Noise pollution levels above 60 dBA can adversely affect health in certain emerging regions, predicted level may reach 90–110 dBA. Negative social behaviors, cardiovascular problems, sleep disorders, and hearing impairment are among the side effects while traffic, industry, and military sonar are important sources. In Ghanaian mining areas like Tarkwa, noise mapping is crucial for determining pollution, supporting planning, and raising public awareness to lessen negative health effects (Baffoe et al., 2022). Other types of pollution like thermal pollution, light pollution, and radiation pollution also have dangerous effects on human health and other organisms (Abolhasani et al., 2021).

Importance of Studying Pollution's Impact on Health

Since both acute and long-term exposure to heavy metals and pollution can cause major health concerns, research is crucial for protecting public health and developing policies that encourage cleaner ecosystems and sustainability (Duruibe et al., 2007). Air pollution, especially PM2.5 and NO_2, is associated with cognitive impairment in older persons, and the effects are exacerbated by proximity to major roadways (Schikowski

& Altuğ, 2020). Exposure to air pollution is associated with serious health concerns; research shows that a 10 μg/m^3 increase in PM2.5 can increase hospitalization rates for respiratory diseases by 8% and the mortality rate from lung cancer by 15–27%. It is imperative to address air pollution because it not only shortens life expectancy but also makes health inequities among vulnerable groups, such as the elderly and children, worse (Hassan Bhat et al., 2021).

Understanding Pollution

Types of Pollutants

Chemical pollutants: include several industrial chemicals that pollute the air, water, and soil, heavy metals, and persistent organic pollutants (POPs) (Naidu et al., 2021).

Biological pollutants: include pathogens and invasive species that disturb ecosystems and endanger human health. Agricultural practices and wastewater discharge are common ways are common pathways for these contaminants (Kumar et al., 2021).

Physical pollutants: including light, noise, and heat pollution, can hurt wildlife and human health. Sources include urbanization, industry, and transportation (Shetty et al., 2023).

Radioactive contaminants: are from nuclear power plants and they can cause genetic alterations and cancer (Hwang et al., 2020).

Nutrient pollutants: primarily excess nitrogen and phosphorus, cause eutrophication leading to oxygen deprivation and toxic algal blooms. Wastewater discharge and agricultural runoff are the main sources (Sakadevan & Nguyen, 2017).

Effect of Air Pollution on Respiratory Health

Particulate matter: microscopic airborne particles are categorized by size:

PM10: Particles (≤ 10 micrometers).

PM2.5: Particles (≤ 2.5 micrometers)(Cetin et al., 2017).

Respiratory Diseases Linked to Air Pollution

Long-term exposure causes DNA damage and chronic inflammation, leading to lung cancer and other health problems (Kim et al., 2018). The effect of air pollution on respiratory health is given in Table 1.

- **Asthma:** A chronic respiratory condition characterized by airway inflammation, and blockage. By causing airway inflammation, raising susceptibility to allergens, and impairing lung function, pollution, from O_3, NO_2, and particulate matter exacerbates asthma, especially in susceptible groups (Tiotiu et al., 2020).
- **COPD (Chronic Obstructive Pulmonary Disease):** A chronic respiratory illness that is frequently associated with high levels of exposure to harmful particles and gases. The incidence and mortality of COPD are greatly increased by prolonged exposure (Duan et al., 2020).

Table 1: Health effects of air pollution on COPD and Respiratory health

Study/ Year	Location	Population Sample	Health Outcomes	Pollutants
(Pope Iii et al., 2002)	USA	500,000 adults	cardiopulmonary, lung cancer	$PM_{2.5}$ (μg/m^3)
(Yang et al., 2005)	Vancouver, Canada	6,027 adults	Daily COPD hospitalization	NO_2 (p.p.b.), CO (p.p.m.)
(Gryparis et al., 2004)	23 European cities	>50 million adults	Daily mortality: Total, respiratory, cardiovascular	O_3 (μg/m^3)
(Gauderman et al., 2004)	California	1,759 children (average age 10)	Pulmonary function and COPD	NO_2 (p.p.b.), $PM_{2.5}$ (μg/m^3), PM_{10} (μg/m^3), CO (μg/m^3)
(Forastiere et al., 2005)	Rome, Italy	5,144 subjects	Fatal, non-hospitalized coronary events	PNC (particles/cm^3), CO (μg/m^3)
(Schikowski et al., 2005)	Germany	4,757 women (55 years old)	Pulmonary function and COPD	NO_2 (μg/m^3), PM_{10} (μg/m^3)
(Doiron et al., 2019)	UK	303,887	Prevalence of COPD	$PM_{2.5}$ (μg/m^3), PM_{10} (μg/m^3), NO_2 (μg/m^3)
(Zanobetti et al., 2008)	USA	1,039,000	Mortality	PM_{10} (μg/m^3)
(Eum et al., 2019)	USA	22,200,000	Mortality	O_3 (ppb)
(Cai et al., 2019)	China	41,815	Excess risk of mortality	$PM_{2.5}$ (μg/m^3)

- **Lung Cancer:** Studies using 'Land Use Regression models' link higher pollution concentrations to an increased risk of lung cancer. Long-term exposure to PM2.5 Cu and PM10 Zn is especially harmful (Raaschou-Nielsen et al., 2016). The effect of air pollution on the lungs is shown in Fig. 1.
- **Respiratory Infections:** PM exposure raises the risk of respiratory infections, like influenza and respiratory syncytial virus. Pollution impairs immune responses, increasing susceptibility, especially in vulnerable groups. Higher hospitalization and morbidity rates from respiratory illnesses correlate with elevated air pollution levels (Domingo & Rovira, 2020).

Vulnerable Population

- **Children:** Air pollution significantly impacts children causing 7.7 million fatalities worldwide, including over 660,000 in children. Their risk arrives from lower detoxification systems that impair their capacity to digest toxic substances, and shorter stature leading to inhalation of concentrated toxins (Goldizen et al., 2016).
- **Elderly:** Older adults' respiratory health is greatly impacted by outdoor air pollution. Short-term exposure to PM10 is linked to a 6-9%

increase in winter COPD admissions, and a 10 μg/m^3 increase in PM2.5 is linked to a 3.1% increase in hospital admissions for acute exacerbations of COPD. The elderly are highly susceptible to air pollution, especially those 75 years of age and above (Simoni et al., 2015). Respiratory effects are given in Table 2.

- **Pre-existing Conditions:** PM2.5 exposure is linked to severe declines in lung function measures, such as FEV1 and PEFR, especially in children with asthma not using inhaled corticosteroids. Short-term exposure to PM resulted in a drop in blood oxygen saturation, especially during the first three hours of exposure, and this drop was more noticeable in COPD patients than in healthy people (Maung et al., 2022).

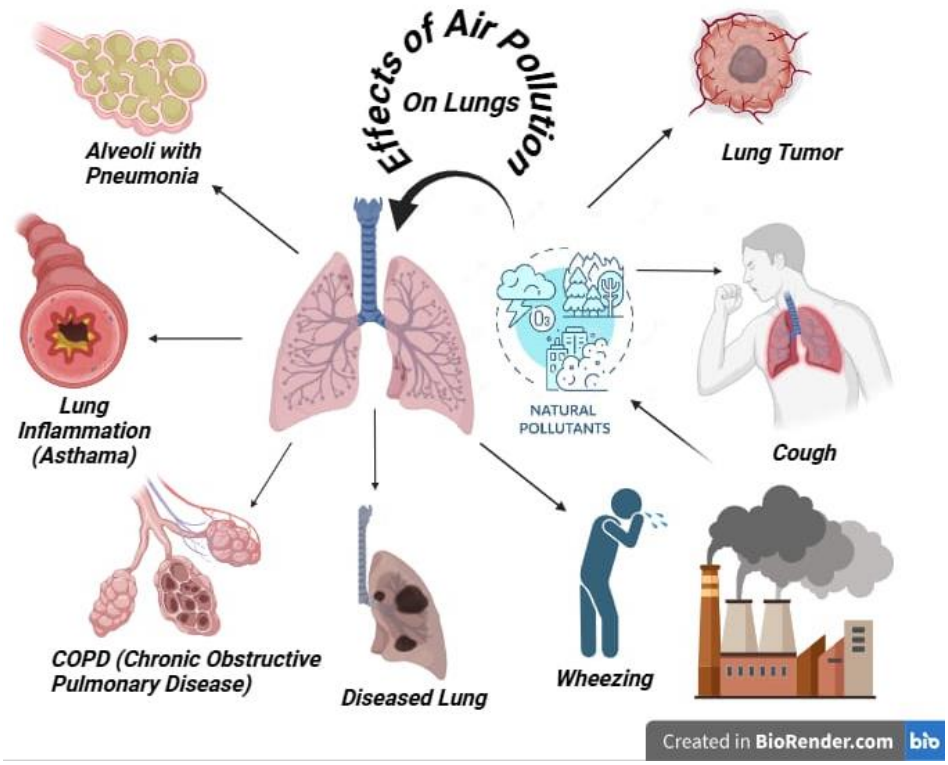

Fig. 1: Lung response to pollution

Table 2: Respiratory Health effects of air pollution

Health affects	Pollutant
Mucosal irritation (adults) (Bascom et al., 1991)	PM, NO_2, NOx, Benzene, 1,3-Butadiene, Fungal spores
Cough, wheeze, shortness of breath (adults) (Littlejohns et al., 1989)	O_3, 1,3-Butadiene, PAHs
Respiratory infections (prenatal) (Korhonen et al., 2019)	$PM_{2.5}$
Respiratory infections (children) (Simoes et al., 2011)	TRAP, PM_{10}, $PM_{2.5}$, NO_2, Indoor air pollution, Fungal spores
Lung function growth (prenatal) (Kreiner-Møller et al., 2014)	$PM_{2.5}$, PM_{10}, NO
Lung function growth (children) (Bisgaard et al., 2012)	TRAP, $PM_{2.5}$, PM_{10}, NO_2, O_3, BMF
Asthma exacerbation (children) (Puranik et al., 2017)	TRAP, $PM_{2.5}$, PM_{10}, NO_2, O_3, Black carbon, Fungal spores
Asthma development (children) (Myers et al., 2019)	O_3, BMF, Fungal spores
COPD development (childhood exposure, adult) (Stocks & Sonnappa, 2013)	Indoor air pollution
Lung cancer (adults) (Kreuzer et al., 1998)	Diesel exhaust, Gasoline exhaust, PM, Trichloroethylene, Radon, Asbestos, Formaldehyde, Black carbon, Styrene, Asphalt, tobacco smoke, Coal combustion, High-temperature frying

Effect of Water Pollution on Intestinal Health

Water contamination in Central Asia has worsened due to old infrastructure and inadequate wastewater treatment, over 70% of water sources are poor. This leads to a high incidence of gastrointestinal diseases, including increased maternal and infant mortality, among

people depending on contaminated water (Bekturganov et al., 2016). Water pollution exposes people to dangerous chemicals and pathogens, negatively impacting health. It can cause cancer, kidney problems, and diarrheal diseases, killing about 1.1 million children annually (Singh & Gupta, 2016).

Mechanism of Impact

- **Ingestion Pathway**

Drinking tainted water can cause toxic effects pollutants frequently find their way into water systems through industrial discharge or fecal contamination (Rodríguez-Tapia & Morales-Novelo , 2017). Intestinal health can be disrupted and long-term digestive problems can result from consuming contaminated food, whether it comes from pesticide-laden produce from agricultural runoff or bio-accumulated heavy metals in seafood (Hirt & Body-Malapel, 2020).

- **Gut microbiota Disruption**

Inflammation, obesity, and metabolic syndrome may develop as a result of environmental pollutants that change the gut microbiota and interfere with the synthesis of vital metabolites for energy metabolism and immune response (Jin et al., 2017). By upsetting beneficial bacteria and encouraging pathogenic species, environmental pollutants such as pesticides and heavy metals can cause dysbiosis in the gut microbiota, which can hurt metabolism, immune responses, and disease susceptibility (Claus et al., 2016).

- **Gastrointestinal Diseases Linked to Water Pollution**

Acute gastroenteritis is characterized as a diarrheal illness. Acute gastroenteritis causes 300 pediatric fatalities, 200,000 hospitalizations, and 1.5 million clinic visits annually in the US (Elliott, 2007). Children aged 0 to 4 have the highest rates of diarrhea linked to swimming in contaminated water, *Enterococcus*-infected water dramatically raises prevalence (Arnold et al., 2016). Chronic intestinal ulceration is a hallmark of inflammatory bowel diseases (IBDs). IBD includes anemia, diarrhea, abdominal pain, bleeding, and weight loss (Pithadia & Jain, 2011). IBD may occur as a result of chemical exposures, particularly those from tainted water, which can activate and deregulate the immune system (Leso et al., 2015) as shown in Table 3. An estimated 31 dangers cause approximately 600 million illnesses and 420,000 deaths globally, making water pollution a major contributor to food-borne illnesses. Unsafe water in food processing is a major cause of disease, especially in low- and middle-income countries (LMICs), and contaminated food accounts for 29% of these instances. Every year, diarrheal illnesses alone cause over 1.5 million fatalities (Cissé, 2019).

Table 3: Effect of air pollution on Gut Health

Condition	Reported Effect	Proposed Mechanism	References
Bowel Cancer	Association between dying from colorectal cancer and proximity to metal industry (RR 1.05)	Carcinogens and toxic substances	(García-Pérez et al., 2020)
Appendicitis	Increased appendicitis after short-term exposure to pollutants (ozone, NO_2, SO_2, PM_{10})	Pro-inflammatory effects of pollutants	(Kaplan et al., 2008)
Bowel Infections	ER visits for acute diarrheal disease in children	Effects of swallowed particles on intestine	(Beamish et al., 2011)
Inflammatory Bowel Disease (IBD)	Increased IBD in young adults exposed to SO_2 (ulcerative colitis), NO_2 (Crohn's disease), PM_{10}	Effects on immune function, infections, gut barrier, microbiota	(Kaplan & Ng, 2017)

Vulnerable Population

- **Children:** Diarrhea from contaminated drinking water, poor sanitation, and poor hygiene habits kill over 829,000 people annually, including nearly 300,000 children under five. This amounts to around 5.3% of all deaths in this age range worldwide (Lin et al., 2022). In a study that examined data from South Africa from 2008 to 2018, the death rate for children fewer than five dropped by 31% as drinking water quality regulations were better followed. Despite advancements, 6.8% of South Africans still do not have access to clean drinking water, which puts children's health at constant risk (Malebatja & Mokgatle, 2022). In a US study with 84,411 participants, 21% of pediatric diarrhea episodes were caused by water exposure. Children aged 0 to 4 were most at risk from recreational water exposure (Arnold et al., 2016).
- **Immuno-compromised Individuals:** Studies in Brazil have shown a connection between diarrheal illnesses and *Cryptosporidium parvum* infections, putting immuno-compromised people especially those with HIV/AIDS at increased risk of gastrointestinal disorders due to tainted water. In vulnerable groups, unsafe water, sanitation, and hygiene have a major impact on morbidity and mortality. An estimated 1.7 million people die from waterborne illnesses worldwide each year, with immune-compromised people being disproportionately affected (Ashbolt, 2015).
- **Communities relying on contaminated water sources:** The Atoyac River's contamination presents serious health problems shown a correlation between elevated levels of total coliform bacteria and a rise in gastrointestinal diseases in neighboring communities, underscoring the perils of depending on this contaminated water source (Ashbolt, 2015). An estimated 1.7 million people die from waterborne illnesses each year worldwide as a result of poor sanitation, hygiene, and water quality, with many of these deaths taking place in areas where tainted water supplies are a major source of water (Lin et al., 2022).

Interconnection between Intestinal and Respiratory Health

- **Gut-lung axis**

According to (Haldar et al., 2023) the two-way connection between gut microbiota and lung health is called the gut-lung axis, as shown in Fig.

2 and it is crucial in immunological homeostasis. Although the phylum of bacterial species (*Firmicutes* and *Bacteroidetes*) is the same in these environments, the species are different. Gut microbiota can affect lung health and imbalance in these increases the risk of respiratory diseases (Enaud et al., 2020). According to (Budden et al., 2017) the gut micro-biome produces short-chain fatty acids when they break dietary fibers can affect lung immunity through immune signals and microbial metabolites.

- **Role of Micro Biome in Health**

The gut microbiome consists of 1000 different types of bacteria. A lot of intestinal and extra-intestinal illnesses are associated with disruptions in the microbiome's composition (D'Argenio & Salvatore, 2015). Beneficial bacteria produce antimicrobial substances resist pathogen reproduction and provide protection from disease (Bull & Plummer, 2014).

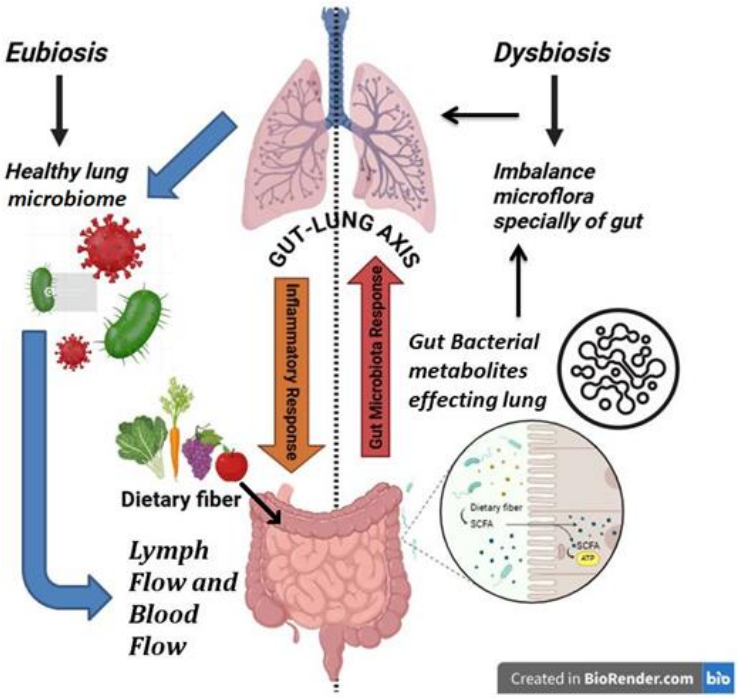

Fig. 2: GUT-LUNG AXIS (A BI-DIRECTIONAL RELATIONSHIP)
(https://www.biorender.com/)

How does Pollution affect both Systems?

- **Shared inflammatory pathways**

Both systems react to contaminants by factors IL-6, TNF-α, and IL-1β. They can facilitate inflammation in the stomach and lungs (Olstrup et al., 2024). Toxins activate the immune system, leading to inflammatory responses that attract immune cells deepening inflammation in both organs (Salim et al., 2014). Oxidative stress is caused by toxins resulting in cellular damage and inflammation in both systems (Crawford et al., 2021).

- **Impact of Pollutants on Microbiota**

Long-term exposure to pollutants causes changes in the richness and diversity of the gut microbiota. Increased O_3 exposure results in increased *Bacteroidaceae* abundance, higher NO_2, increase in *Coriobacteriaceae* (Filardo et al., 2022). In mouse models, exposure to PM10 results in dysbiosis decreases *Bacteroidetes* richness, and increases *Firmicutes* and *Verrucomicrobia*. The PM2.5 exposure causes a decrease in *Lactobacillus* and increases the *Rikenellaceae*, which can result in several health issues (Feng et al., 2020).

- **Cross-reactivity of Immune Responses**

Respiratory immune responses may be impacted by systemic inflammation brought on by gut dysbiosis. Immune cells and cytokines can affect respiratory inflammation from the gut to the lungs (Rio et al., 2024). Pollutants can cause the release of inflammatory mediators, which exacerbate inflammation in the respiratory and gut systems and connect gastrointestinal illnesses to respiratory diseases. Gut dysbiosis impairs immunological control, making people more vulnerable to respiratory disorders and highlighting how intertwined these systems are (Serafini et al., 2022).

Case Studies and Research Findings

- **Epidemiological studies**

Respiratory infections are more common in people with higher particulate matter (PM2.5) levels. Incidence of respiratory diseases can significantly increase with a 10 $\mu g/m^3$ increase in PM2.5 making people more vulnerable to respiratory syncytial virus (RSV) and influenza (Monoson et al., 2023). A higher risk of developing IBD has been linked to prolonged exposure to pollutants such as PM2.5 and NO_2, with multiple studies finding statistically significant relationships (Salim et al., 2014).

- **Experimental Studies**

Regulated ozone exposure reduces lung function and increases airway inflammation (Rom et al., 2013). resulted in lower forced vital capacity and forced expiratory volume (Hackney et al., 1975). Exposure to PM and ozone alters the way immune cells, including dendritic and macrophage cells, function, impairing immunological responses (Rom et al., 2013).

- **Real-world Examples**

Burning high-sulfur coal resulted in a major air pollution episode known as the 'Great Smog of London' in December 1952. An estimated 12,000 people died from respiratory and cardiovascular illnesses as a result of the five days of smog. During the event, there was a reported 163% increase in respiratory disorders and a 48% increase in hospitalizations for respiratory problems (Javed et al., 2021). The 'Donora smog' incident in Pennsylvania in October 1948 caused 400 hospitalizations, 20 fatalities, and 5,000 to 7,000 illnesses in locals. More than 500,000 individuals were exposed to poisonous methyl isocyanate during the 'Bhopal tragedy' in India, which led to both short-term respiratory distress and long-term health problems (Javed et al., 2021).

Preventive and Mitigation Strategies

- **Policy Recommendations**

Stronger emissions regulations for vehicles, industry, and power plants must be implemented in line with WHO guidelines. Regular inspections, open reporting, and the establishment of robust water quality standards and monitoring systems will empower communities to take the necessary actions against contaminated air and water (Burns et al., 2019).

- **Public Health Campaigns**

When communities learn about the health risks, they are urged to take preventative measures, and social media and apps are vital tools. Working together with non-governmental organizations, academic institutions, and medical facilities can improve health education programs and increase community involvement (Ramírez et al., 2019). Workshops and forums encourage community discussion and cooperation with health officials to address local pollution concerns, and educational materials distributed in schools and healthcare facilities help vulnerable people learn about the consequences (Bouza et al., 2022).

- **Individual Actions**

By carefully planning outside activities, enhancing indoor air quality with ventilation and air purifiers, and avoiding dangerous indoor pollutants, people can minimize their exposure (Janjua et al., 2021). Community involvement through campaigning and interaction with politicians is crucial for advocating for stricter pollution legislation and protections, wearing N95 masks can assist shield vulnerable people (Bouza et al., 2022).

Conclusion

Our respiratory and digestive systems are both severely impacted by pollution, which upsets the equilibrium our bodies require to remain healthy. Pollution affects the very systems that support human life, not just ecosystems. Pollutants affect gut microbiota, impair respiratory function, and upset immune balance in everything from the air we breathe to the water we drink. These effects disproportionately affect vulnerable groups, such as children and the elderly, underscoring health disparities. Stricter laws, increased public awareness, and individual acts must be our top priorities to address this. We can promote healthier lives and cleaner ecosystems by realizing how intertwined our body systems are with the environment.

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