International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Air Quality Effects on Respiratory Health

Mohammad Tauheed Alam

Student, Prayagraj 211003, India

ABSTRACT

Purpose of the Review : In this paper, I wanted to bring together what different studies say about how breathing bad air—whether from outside sources or at work—affects people's lungs. A lot of this includes research from long-term health tracking, short-term daily data, and reports about what's in the air in different places. I'm mostly focusing on pollutants like $PM_{2.5}$, PM_{10}, sulfur dioxide, nitrogen gases, ozone, and stuff like asbestos or silica, since these seem to be tied to breathing issues in lots of different groups.

Recent Findings : There's now strong evidence connecting air pollution to asthma, COPD, lung infections, and even lung cancer. In places like Delhi, India, PM_{10} levels go way beyond what's considered safe—sometimes 10 times over. Not surprisingly, over 32% of city kids there report breathing issues, while that number is just around 18% in the countryside. Winter tends to be worse for people with lung issues, mostly because pollution spikes then. A study from Poland that followed over two million births found that babies born in heavily polluted areas were almost twice as likely to die from breathing-related illnesses (HR around 1.96). Other studies using daily tracking methods showed that even a small increase—like 10 micrograms per cubic meter of PM_{10}—was linked to a rise in hospital visits. SO_2 was even worse, with some models showing an 83% increase in hospital visits over six days (RR = 1.83). On the job, people who are around asbestos, silica, or harsh chemicals are still getting conditions like pneumoconiosis and work-related asthma.

Summary : Air pollution—both ambient and occupational—significantly contributes to respiratory morbidity and mortality, particularly among children, the elderly, and lower-income populations. Coordinated air quality policies, stronger environmental regulations, and targeted public health interventions are urgently needed to mitigate exposure and reduce the global respiratory disease burden.

Keywords: Ambient air pollution, Respiratory morbidity, Particulate matter exposure, Urban Pollution, Sulphur dioxide toxicity

1. Introduction

I've read a lot about air pollution recently, and honestly, I didn't realize how bad it is worldwide. Cities like Delhi and Beijing are always in the news, but even smaller cities are affected. The World Health Organization says that over 90% of people living in cities are breathing air that isn't actually safe [(*WHO*, 2016.). That's leading to millions of early deaths every year—more than 3 million, in fact. One of the biggest culprits is something called particulate matter, especially PM2.5 and PM10. These fine particles have a strong link to respiratory diseases and have been shown to increase the risk of death from breathing-related problems [2]. The situation is worse in developing countries, where rapid growth in population, cars, and industries often happens faster than governments can introduce proper pollution control measures (Mittal A, Arora A, Mandal A, 2004)

Delhi is one example where this problem is clearly visible. It's regularly ranked among the world's most polluted capitals, and the city often experiences pollution levels that go far beyond national and WHO limits [4]. This exposure has led to an increase in health issues like asthma, COPD, lung cancer, and infections of the lower respiratory tract [5]. The people who suffer the most from this are usually children, the elderly, and those from low-income areas [6]. Studies have confirmed that exposure to polluted air—whether over a short period or for years—can lower lung function, increase hospital visits, and raise the risk of dying early [5]. Children, especially, face long-term lung damage because their lungs are still developing, and that early exposure can have lasting effects [7].

Honestly, it's not just the air outside that's a concern. In a lot of occupation —like working in factories or around dust and chemicals—people breathe things that aren't safe at all. Most of the time, they don't even realize how harmful it is until years later. These kinds of exposures can build up slowly and end up causing serious lung issues like occupational asthma or even conditions like pneumoconiosis and some cancers [8]. And when you combine all that with outdoor air pollution, the health risks become way worse [5].

Researchers have been trying to study these effects more closely. They're using things like time-series analysis and models like GAMs to figure out how pollution and health are connected. Studies in countries like India, China, and some European nations are helping with this [9]. But even though we know a lot more now, most countries still haven't done enough with policies or actions to fix the problem [10].

That's why I decided to focus this paper on what current research says about the health impact of air pollution—both from the environment and from jobs. It's important to know what pollutants cause the most harm and which groups are the most affected, so better plans can be made to protect people.

2. Study Settings & Exposure Assessment

If you really want to study how air pollution messes with people's lungs, you've got to focus on places where the air is honestly bad—and Delhi's definitely one of them [11]. It's a packed city, more than 11 million people living close together, and it's known for rough air quality. In one study I read about, they watched five different kinds of pollutants [12]. I remember $PM_{2.5}$ and PM_{10} (the little and not-so-little dust particles), plus gases like nitrogen dioxide, sulfur dioxide, and carbon monoxide. They pulled in data from 11 different spots across the city, every single day, for almost three years—from 2016 to 2018 .

But pollution doesn't stay the same every day—it depends on the weather too. So the team also tracked stuff like temperature, humidity, wind, and even rain. That way they could adjust for those things and not let weather throw the whole study off [13]. Health outcome data consisted of daily counts of outpatient visits for all respiratory diseases (ICD-10 J00–J99) at a major tertiary hospital, stratified by age: young adults (≤ 44 years), middle-aged (45–64 years), and elderly (≥ 65 years) [14]. To capture urban–rural contrasts in respiratory morbidity, a large cross-sectional survey enrolled 11,628 schoolchildren (age 6–17 years) from 36 schools across Delhi, selected to represent low, medium, and high socioeconomic strata and located within a 3 km radius of air monitors (*Central Pollution Control Board (CPCB). National Air Quality Monitoring Programme (NAMP): Delhi Air Quality Data 2016–2018,* 2016). Indoor PM_{10} levels were measured in the children's homes using portable aerosol photometers, while ambient levels of PM_{10} and sulfur/nitrogen oxides were obtained from local pollution control boards [16]. A control group of 4 536 rural children from West Bengal and Uttaranchal—areas with minimal industrial activity and predominantly liquefied petroleum gas for cooking—allowed direct urban–rural comparison of respiratory symptom prevalence [17]. Beyond local studies, a nationwide retrospective birth cohort in Poland linked 2 277 585 live births (2012–2017) to 9 427 recorded infant deaths, identifying 248 deaths due to respiratory diseases (ICD-10 J00–J99) in the first year of life [18] . Industrial exposure was quantified as county-level Total Particle Pollution (TPP), encompassing all industrial dust, metals, and hydrocarbons, reported annually in tons/km². Birth and death records were matched on birth date, sex, birth weight, gestational age, maternal age, and county of residence, achieving a 99.76% linkage rate [19]. TPP quintiles (Q1–Q5) provided a proxy for industrial emissions, enabling survival analysis of infant mortality in relation to pollution burden .

3. Epidemiological Evidence

3.1 Urban–Rural Symptom Comparisons

Multiple community-based surveys demonstrate that urban air pollution markedly increases respiratory symptom prevalence compared with rural settings. Over a recent three-month period, children in Delhi were about 70 percent more likely to report respiratory complaints than their counterparts in rural West Bengal—a difference so pronounced it couldn't be chalked up to chance ($P < 0.001$)10. Not only did urban youngsters experience runny noses and sore throats more often, but they also suffered wheezing and lingering coughs at roughly one and two-thirds times the rate seen in the rural group, with the study's confidence bounds running from 1.32 up to about 1.93. Lung function tests showed restrictive patterns in 22.5% of the Delhi children, nearly double the 11.4% found in rural children. Similarly, obstructive issues were seen in 10.7% of urban participants compared to 6.6% in the rural group, while a combination of both patterns was found in 7.1% versus 2.0% .

Spirometry revealed restrictive deficits in 22.5% of Delhi children versus 11.4% in controls, obstructive deficits in 10.7% vs. 6.6%, and combined deficits in 7.1% vs. 2.0% [7]. Non-respiratory health effects—hypertension (36% vs. 9.5%), chronic headaches, eye irritation, and skin problems—were also elevated among urban participants and showed positive correlations with ambient PM_{10} levels [20].

3.2 Time-Series & Generalized Additive Models

Time-series studies employing Generalized Additive Models (GAMs) have elucidated short-term pollutant–health associations while adjusting for nonlinear confounders. In one Delhi study, each 10 µg/m³ increase in SO_2 was linked to a 32.6% rise in same-day respiratory hospital visits and an 83.3% cumulative increase over six days (lag 0–6), controlling for seasonal trends, temperature, humidity, wind speed, and day of week [21]. PM_{10} effects were smaller yet significant—a 10 µg/m³ rise led to a 0.21% cumulative increase in visits (lag 0–6) [22]. These models highlight both immediate and lingering morbidity effects of gaseous and particulate pollutants.

Separately, GAM-based analyses in Chinese and European cities confirmed that short-term peaks in $PM_{2.5}$, NO_2, and O_3 are robustly associated with increased emergency department visits for asthma, COPD exacerbations, and respiratory infections, even at concentrations below national standards [23].

3.3 Infant Mortality & Industrial Exposures

The Polish birth cohort provided compelling evidence linking industrial emissions to infant respiratory mortality. When we first examined the raw data, infants in the top 20 percentile of particulate pollution had a roughly 78 percent greater chance of dying from respiratory causes than those in the bottom 20 percentile—a gap too large to be random (HR 1.78, 95 percent CI 1.18 to 2.70; $p = 0.006$) [24]. Bringing in individual details—baby's sex, birth weight, weeks at birth and mother's age—barely changed things, with the elevated risk still hovering at about 80 percent (HR 1.80, 95 percent CI 1.21 to

2.68; $p = 0.004$). Once we layered on community factors like how urban the county was, local unemployment rates and how densely people lived, the hazard crept up even more, pushing the most-exposed infants to nearly twice the baseline risk (HR 1.96, 95 percent CI 1.06 to 3.63; $p = 0.032$) [23]. Notably, the survival curves for highly exposed versus minimally exposed babies split most sharply between roughly day 50 and day 150 of life—pinpointing that two- to five-month window as a critical period of vulnerability [25].

4. Vulnerable Populations & Life-Stage Effects

4.1 Children

Children's respiratory systems are uniquely sensitive: roughly 80% of alveolar structures develop by age six, with growth continuing into adolescence [26]. Early-life exposures to inhaled pollutants can disrupt alveolarization and airway remodeling, leading to lifelong deficits in lung function. In Delhi, 32.1% of children reported respiratory symptoms versus 18.2% in rural controls, with girls disproportionately affected (female : male ratio 1.21 vs. 1.30) . Logistic regression revealed that PM_{10} concentrations above 125 µg/m³ doubled to tripled the odds of lower respiratory symptoms, establishing a clear dose–response relationship.

Longitudinal cohorts in Europe and North America link high $PM_{2.5}$ exposure to significantly reduced forced expiratory volume in one second (FEV_1) gain over eight years—children in high-exposure areas had a five-fold greater odds of suboptimal lung function (< 80% predicted) at age 18 [27].

4.2 Prenatal & Infant Impacts

During pregnancy, inhaling polluted air full of tiny specks can make a mother's body go on high alert, triggering inflammation and stress at the cellular level. That response can slow down the placenta's work—think of it like a filter that's starting to clog—so the baby may not get as much oxygen or nourishment as it needs to grow on schedule . And when these little ones come early or underdeveloped, their lungs haven't had enough time to finish growing—there's less surface area for gas exchange and not enough surfactant to keep airways open—so they're far more vulnerable to serious respiratory infections and even death in those first fragile weeks of life .

4.3 Elderly & Comorbid Individuals

On the other end of the lifespan, older adults and people already dealing with heart or lung disease feel these tiny pollutants even more acutely. As we get older, our natural "self-cleaning" in the airways slows down and our antioxidant defenses weaken, so inhaled particles stir up a stronger inflammatory response. The result - More flare-ups of COPD, more trips to the hospital, and sadly, higher death rates. One large review even found that every 10 µg/m³ bump in $PM_{2.5}$ was linked to about a 0.31 percent rise in COPD-related hospital visits [2].

5. Pollutant Composition & Biological Mechanisms

5.1 Criteria Pollutants & Emission Sources

When we look at the smoggy mix in our air, six names keep popping up on every regulator's watchlist: those specks of particulate matter (from grit you can see with your eyes down to microscopic soot), ozone lurking at ground level, sulfur dioxide, the nitrogen oxides, carbon monoxide—and even old-school lead. A lot of this grime comes straight off tailpipes, stacks at factories or the plume from burning wood and crop leftovers. But sometimes the nastiest bits aren't emitted directly; they form later when sunlight and oxygen spark chemical reactions among those same factory and vehicle gases, creating ozone in the open air. And don't forget the pollution inside your own home—smoke from cooking fires, a roommate's cigarette, or even the off-gassing of new paint and building materials can add to your personal "air bill," especially where cleaner fuels or ventilation are hard to come by (28,29).

5.2 Pathophysiological Pathways

Once the tiniest $PM_{2.5}$ specks slip past the throat and windpipe, they settle deep in the alveoli—the lung's microscopic air sacs—where they stir up trouble. Those particles spark a burst of reactive oxygen species (ROS), rouse the resident immune cells and send out distress signals (like IL-6 and TNF-α), all of which can damage delicate tissue [30]. Imagine your lungs' natural cleaning crew—the cilia—getting gummed up, so mucus and germs stick around longer than they should. Meanwhile, gases like ozone and nitrogen dioxide nick the airway lining directly, nudging cells toward a stubborn, scar-like repair process and shifting immune responses in ways that make breathing feel tight and wheezy [31].

But the story doesn't end in the lungs. That inflammation can spill into the bloodstream, where it wears on vessel walls, speeds up plaque formation and raises the risk of heart attacks, strokes and other serious cardiovascular problems—all alongside the respiratory harm we see first hand [32].

6. Disease-Specific Outcomes

6.1 Asthma

Air pollution—whether you're inhaling exhaust fumes on a busy street or dust kicking up on a factory floor—can turn a mild wheeze into a full-blown asthma attack. In animal experiments, fine particles and ozone have been shown to act like an allergic "turbocharger," ramping up airway inflammation and sensitivity. In people, even a ten-unit increase in $PM_{2.5}$ can translate into roughly a one to two percent rise in emergency visits for asthma [33]. Children raised near heavy traffic tend to develop asthma more often than those in quieter neighborhoods, although large studies like ESCAPE sometimes report mixed results (34,35). And on hot, sunny days when ozone concentrations climb, pediatric wards often see a surge of wheezing kids—which is why many health agencies now push for real-time air quality alerts for families managing asthma [36].

6.2 Chronic Obstructive Pulmonary Disease (COPD)

In many communities around the world, the smoke from burning wood, crop stalks or dung inside homes drifts into living spaces and settles deep in people's lungs over years—scarring delicate airways and quietly leading to chronic breathing problems, even among those who've never had a cigarette in their hand. Alongside tobacco smoke, these everyday household fumes are a hidden driver of COPD in non-smokers, underscoring just how essential truly clean air is both at home and on the job. Outdoors, every 10 $\mu g/m^3$ rise in larger particles (PM_{10}) translates into more flare-ups and sadly, more deaths among those already struggling with lung function [37]. On the job, dusty environments—think mining, construction or manufacturing—account for nearly a third of COPD cases in non-smokers, reminding us that workplace air quality is just as critical as quitting smoking [38].

6.3 Lung Cancer

It might surprise some, but the air we breathe outside is officially labeled a carcinogen by the World Health Organization's cancer arm (IARC) alongside tobacco smoke. That label comes from solid evidence: each 10 $\mu g/m^3$ bump in $PM_{2.5}$ is tied to an 8–23 percent rise in lung cancer deaths [39]. Traffic pollutants—nitrogen dioxide, sulfur dioxide and fine soot—also show up again and again in studies as independent risks, even after factoring out smoking habits. At the same time, certain jobs expose people to asbestos, silica dust and other known cancer-causing agents, which fuel chronic inflammation and DNA damage over years on the factory floor [40].

6.4 Respiratory Infections

When traffic fumes rise or ozone levels creep up, it isn't just asthma sufferers who feel the pinch—young children and older adults often wind up in emergency rooms with coughs, fevers, and other breathing troubles [41]. Over the long haul, breathing in fine particles ($PM_{2.5}$) and nitrogen dioxide can even make COVID-19 worse. These pollutants seem to crank up the number of "doors" (ACE2 receptors) the virus uses to get into our cells, gum up the little hairs that sweep germs from our lungs, and push our immune system toward an over-excited response that can do more harm than good [42].

7. Seasonal & Geographic Patterns

Air quality wears different "seasons" on its sleeve. In Delhi and much of North India, winter's cold layers trap smoke from crop burning and other sources close to the ground, so particles like PM_{10} and $PM_{2.5}$ spike just when cases of asthma, COPD flare-ups and pneumonia also climb [43]. Beijing sees a similar winter haze, yet flips to photochemical smog and higher ozone readings in the summer heat [44]. Pollution doesn't respect borders, either—dust kicked up in the Sahara can drift all the way to the Caribbean, proving that clean air is a team sport. With global temperatures on the rise, we're likely to see more ozone cooked up in sunlight too, making it even tougher to keep our lungs happy everywhere [45].

8. Control Measures & Policy Implications

Effective reduction of respiratory disease burden demands multi-sectoral interventions. In Delhi, policy measures include unleaded petrol mandates, catalytic converters for vehicles, adoption of compressed natural gas for public transport, progressive implementation of Bharat Stage emission norms, and the creation of an Air Ambience Fund to finance pollution control projects [46]. Judicial interventions have enforced the closure of noxious industries and regulated brick kilns. Collaboration with NGOs (e.g., Centre for Science and Environment, The Energy and Resources Institute) and academic institutions (e.g., Indian Institutes of Technology, CSIR labs) has enhanced air quality monitoring and public awareness [11].

Evidence shows that large-scale interventions yield health benefits: clean-indoor air initiatives reduce respiratory symptoms after short exposures, and introduction of lower-emission vehicles is linked to significant gains in disability-adjusted life years [7]. Strategic air quality management—guided by exposure–response data from GAMs and cohort studies—should be integrated into urban planning, transportation policy, and health advisory systems to protect vulnerable populations [13].

9. What We Don't Really Know Yet

People have studied air pollution a lot, yeah, but still—some parts we honestly don't get. Like in underdeveloped countries, the air quality index is bad, and kids grow up breathing it every day. But who's actually following them for years? Not many. So we don't really know what all that exposure does long-term. It's kind of a blank space.

Also, the kinds of pollutants are changing. It's not just smoke and car exhaust anymore—there are chemicals from plastic, factories, and other stuff in the air now. We honestly don't know much about how these affect the lungs.

Air pollution and climate change are connected too, but most research treats them separately. If we had better models that combined both, we could probably do more to prepare for future health problems.

And then there's the link with infections. COVID showed us that polluted air might make some diseases worse. But we don't really understand why yet. Finally, we need to test the solutions more. Like, does switching to clean stoves or planting trees actually lower hospital visits for breathing problems. That's the kind of evidence we need for smart policies.

10. Conclusion

Breathing clean air is still far from reality in many parts of the world, especially in cities like Delhi, where pollution from vehicles, industries, and other sources continues to affect people's lungs. This review highlights how exposure to pollutants like $PM_{2.5}$, PM_{10}, and SO_2 is linked to more cases of respiratory illness, particularly during colder seasons. Children living in densely polluted zones often show more symptoms than those in rural areas. Workplace hazards and lack of awareness make things worse. While some progress has been made through transport changes and environmental regulations—it isn't enough. Real change needs consistent public involvement, better rules, and cleaner technologies. The air we share doesn't stop at city borders, so fixing this problem means thinking both locally and globally, with a focus on protecting health before disease takes hold.

Acknowledgements

The author conducted this review independently and gratefully acknowledges the contributions of all researchers and scholars whose work has informed and supported this paper. Their valuable studies and insights formed the foundation for this analysis of air quality and respiratory health.

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