

THE IMPACT OF AIR POLLUTION ON THE INCIDENCE AND PROGRESSION OF UPPER RESPIRATORY TRACT DISEASES IN URBAN POPULATIONS – NARRATIVE REVIEW

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ABSTRACT

BACKGROUND

Air pollution remains a major environmental health factor in urban populations, with sustained exposure to particulate matter and gaseous pollutants. The upper respiratory tract is directly exposed to inhaled pollutants and represents a primary site of interaction between environmental factors and mucosal inflammation.

AIMS

To provide a clinically oriented analysis of the association between urban air pollution and upper respiratory tract diseases, including chronic rhinosinusitis, allergic rhinitis, and acute sinusitis, with assessment of clinical outcomes, pathophysiological mechanisms, vulnerable populations, and limitations of the current evidence base.

METHODS

A narrative review with a structured literature search was conducted using PubMed, Google Scholar, and ResearchGate. The search covered studies published between 2016 and 2025, with inclusion of selected earlier landmark studies. Eligible studies included cohort, case control, time series studies, randomized trials, as well as systematic reviews and meta analyses evaluating incidence, progression, and clinical outcomes of upper respiratory tract diseases in relation to ambient air pollution. A total of 44 studies were included in the final synthesis after screening and eligibility assessment.

RESULTS

Consistent associations were identified between exposure to particulate matter and gaseous pollutants and increased incidence, symptom severity, and healthcare utilization in chronic rhinosinusitis and allergic rhinitis. Effect estimates for particulate matter were generally modest, with odds ratios around 1.2 for PM10, while nitrogen dioxide showed stronger associations in selected analyses. Short term exposure to PM2.5 and NO2 was linked to increased outpatient visits and symptom exacerbations, particularly in children. Long term exposure was more consistently associated with disease persistence and severity, including increased likelihood of surgical interventions in chronic rhinosinusitis. Evidence for acute sinusitis remains limited and heterogeneous. The main sources of variability across studies include differences in exposure assessment, diagnostic criteria, and control of confounding factors.

CONCLUSIONS

Urban air pollution is a clinically relevant factor associated with the burden and course of selected upper respiratory tract diseases, particularly chronic rhinosinusitis and allergic rhinitis. The strength of evidence is highest for chronic rhinosinusitis, moderate for allergic rhinitis, and limited for acute sinusitis. Current data support consideration of environmental exposure in clinical interpretation of disease dynamics, while remaining insufficient to justify direct modification of standard treatment algorithms. Further prospective and interventional studies with standardized methodology are required to clarify causal relationships and improve clinical applicability.

Keywords: air pollution, upper respiratory tract diseases, chronic rhinosinusitis, allergic rhinitis, acute sinusitis, PM2.5, PM10

INTRODUCTION

Air pollution is a major environmental risk factor contributing to respiratory morbidity worldwide [1],[2]. The upper airway, including the nasal cavity and paranasal sinuses, is directly exposed to inhaled pollutants, making it particularly vulnerable to inflammatory injury [2],[3]. Epidemiological studies indicate that particulate matter, especially PM10, is associated with an increased prevalence of chronic rhinosinusitis and other ear, nose and throat (ENT) conditions [2]. Additionally, exposure to elevated PM2.5 and PM10 levels has been linked to increased upper respiratory symptoms, supporting a role of air pollutants in sinonasal disease burden [3]. Mechanistic evidence suggests that particulate matter disrupts epithelial barrier integrity and promotes pro-inflammatory cytokine release within the sinonasal mucosa, contributing to chronic inflammation [2],[4]. Despite the growing body of evidence, the relationship between urban air pollution and the incidence and clinical course of sinusitis remains incompletely defined, particularly in terms of causal inference and clinical applicability [1],[2]. This review aims to synthesize current evidence regarding the association between urban air pollution and upper respiratory tract diseases, with a particular focus on sinonasal pathology, clinical outcomes, and underlying biological mechanisms. For the purpose of this review, the term upper respiratory tract diseases (URTDs) refers specifically to chronic rhinosinusitis, allergic rhinitis and acute sinusitis. Infectious conditions such as upper respiratory tract infections (URTI) are discussed only in the context of broader upper airway responses to pollution and are interpreted separately.

RELEVANCE AND NOVELTY

Although numerous systematic reviews and meta-analyses have examined the relationship between air pollution and respiratory diseases, most have focused on pooled quantitative risk estimates or lower respiratory tract conditions. In contrast, upper respiratory tract diseases, including chronic rhinosinusitis, allergic rhinitis, and acute sinusitis, remain comparatively underrepresented in clinically oriented syntheses.

The added value of this narrative review lies in several aspects. First, it provides a structured and disease-specific analysis of URTDs, distinguishing between different clinical entities rather than treating them as a homogeneous group. Second, it integrates epidemiological findings with mechanistic insights, allowing for a more comprehensive interpretation of observed associations. Third, the review incorporates clinically relevant outcomes, including quality of life, surgical interventions, and healthcare utilization, which are often not systematically addressed in quantitative meta-analyses.

Additionally, this review emphasizes real-world urban exposure scenarios, including both short- and long-term exposure, as well as interactions between air pollution and aeroallergens. Particular attention is given to vulnerable populations and regional variability, including data from Central and Eastern Europe.

AIM

The aim of this narrative review is to provide a clinically oriented analysis of the association between urban air

pollution and upper respiratory tract diseases, including chronic rhinosinusitis, allergic rhinitis, and acute sinusitis.

Research objectives

1. To assess the association between exposure to major air pollutants and the incidence and progression of these diseases.
2. To analyze the impact of air pollution on clinical outcomes, including symptom severity and healthcare utilization.
3. To summarize current evidence on pathophysiological mechanisms and vulnerable populations.
4. To identify limitations of existing studies and key gaps in the evidence base.

METHODOLOGY

THIS STUDY WAS CONDUCTED AS A NARRATIVE REVIEW OF THE LITERATURE.

A structured search was performed using PubMed, Google Scholar, and ResearchGate databases. The search was conducted in January 2025. The following search strategy was applied: ("air pollution" OR pollutants OR "particulate matter" OR PM2.5 OR PM10 OR "nitrogen dioxide" OR ozone OR "sulfur dioxide" OR "carbon monoxide") AND ("upper respiratory tract disease" OR "chronic rhinosinusitis" OR "allergic rhinitis" OR "acute sinusitis" OR "otitis media") AND (urban OR "metropolitan populations").

The search was limited to studies published between 2016 and 2025. Additionally, two earlier landmark studies (1990 and 2007) were included to provide historical context. Only articles published in English were considered. A manual search of reference lists of relevant articles was also performed to identify additional studies not captured in the database search.

Inclusion criteria comprised observational studies (cohort, case control, and time series), randomized controlled trials, as well as systematic reviews and meta analyses reporting on the incidence, progression, or clinical outcomes of upper respiratory tract diseases in relation to ambient air pollution exposure.

Exclusion criteria included studies focusing exclusively on occupational or industrial exposure, studies addressing only lower respiratory diseases without upper airway involvement, and publications lacking clinical or epidemiological outcomes, such as purely molecular or laboratory based studies. Case reports, editorials, conference abstracts, and expert opinions were also excluded.

The initial search identified approximately 140 records. After removal of duplicates, 115 articles remained for title and abstract screening. Following this stage, 62 full text articles were assessed for eligibility. Ultimately, 44 studies were included in the final synthesis. Thus, a total of 44 sources were finally included in this narrative review.

The most common reasons for exclusion were: lack of relevant clinical outcomes (n ≈ 15), focus on lower respiratory diseases without upper airway involvement (n ≈ 7), non urban or occupational exposure settings (n ≈ 4), and insufficient methodological relevance (n ≈ 2).

Included studies were categorized according to study design, and findings were interpreted with consideration of their respective levels of evidence. Due to the narrative nature of the review, no formal risk of bias assessment or meta-analysis was performed.

Particular attention was given to potential confounding factors, including smoking status, socioeconomic status, and comorbidities. However, these variables were inconsistently reported across studies and could not be uniformly controlled for, which represents a limitation of the available evidence.

RESULTS

A total of 44 studies were included in the final synthesis following the predefined selection process. The characteristics of the included studies are presented in Table 1.

Table 1. Characteristics of included studies evaluating the association between air pollution and upper respiratory tract diseases (URTDs)

Author, year	Study design	Country	Sample size	Disease	Study outcome
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Mengxue Lu et al. 2020[5]	Epidemiological study	China	183,943 hospital records	Chronic rhinosinusitis	Increased outpatient visits associated with short-term exposure to NO ₂ and PM2.5, particularly in children
Evelyn M Leland et al. 2021[6]	Narrative review	The USA	N/A	Chronic rhinosinusitis	Air pollution, especially particulate matter, may contribute to inflammation and worsening of CRS
S. Peeters et al. 2022[7]	Observational epidemiological study	Belgium	278 patients	Chronic rhinosinusitis	Higher pollutant exposure associated with increased symptom severity, influenced by season and patient characteristics
Qinfeng Zhou et al. 2024[9]	Prospective cohort study	China	367,298	Chronic rhinosinusitis	Long-term air pollution exposure increases risk of CRS, particularly with nasal polyps

The included studies demonstrate consistent associations between air pollution exposure and upper respiratory tract diseases, although the strength of these associations varies depending on study design, population characteristics, and type of pollutant.

DISEASE-SPECIFIC ASSOCIATIONS

The available evidence demonstrates consistent associations between exposure to ambient air pollution and the incidence and progression of specific upper respiratory tract diseases.

CHRONIC RHINOSINUSITIS (CRS)

Chronic rhinosinusitis represents one of the most extensively studied upper respiratory tract conditions in relation to air pollution exposure. Epidemiological evidence suggests that elevated concentrations of PM2.5 and PM10 correlate with higher prevalence of chronic rhinosinusitis and more severe sinonasal symptoms in affected individuals [6],[7], [10]. Population-based studies have further linked chronic exposure to fine particulate air pollution with increased risk of upper respiratory tract disease onset and severity, reflecting altered mucociliary clearance and persistent mucosal inflammation [9].

Among specific pollutants, nitrogen dioxide has been reported in large-scale population studies to be associated with increased odds of chronic rhinosinusitis, with some analyses suggesting up to a 5.40-fold increase in disease odds per 0.1 ppm elevation in concentration [11],[12],[13],[14]. In comparison, particulate matter exhibits significant but generally lower magnitudes of association for disease onset, such as an OR of 1.22 for PM10, while exposure to PM2.5 has been linked to a 1.89-fold increased risk of requiring revision sinus surgery [12],[15],[3].

ALLERGIC RHINITIS AND ACUTE SINUSITIS

Allergic rhinitis and acute sinusitis are influenced by environmental exposures, with air pollution acting as a contributing factor to their development and exacerbation. The interaction between chemical pollutants and biological aeroallergens constitutes a critical synergistic risk factor for the incidence and progression of upper respiratory tract diseases in urban centers [16],[12]. Allergic rhinitis is characterized by IgE-mediated responses to aeroallergens (pollens, mites, mould), and air pollution may aggravate these inflammatory processes within the upper respiratory tract. [17],[12]. In addition, climate- and pollution-driven changes in pollen and mould, including increased load, prolonged seasons, and enhanced allergenicity, further intensify symptoms in sensitized individuals, particularly in

children [18]. In contrast, specific pollutants demonstrate differential associations with disease entities, as carbon monoxide shows the highest correlation with the incidence of acute sinusitis, while sulfur dioxide is most strongly associated with allergic rhinitis [19],[13].

A comparative analysis of pollutant-specific effects, including effect sizes and study designs, is presented in Table 2.

Table 2. Pollutant-specific associations with upper respiratory tract diseases (URTDs), including effect sizes and study characteristics. URTI are presented as a subset of URTDs.

Pollutant	Disease	Clinical outcome	Effect size	Study design	Source
PM10	Chronic rhinosinusitis	Increased prevalence	OR 1.22	Meta-analysis	[12]
PM2.5	Acute upper respiratory conditions	Emergency room visits	+0.19% per 10 µg/m ³ (lag0)	Time-series	[15]
NO ₂	Chronic sinusitis	Increased prevalence	OR 1.091	Meta-analysis	[12]
SO ₂	Allergic rhinitis	Increased prevalence	OR 1.116	Meta-analysis	[12]
CO	URTI (pediatric subset of URTDs)	ED visits	IRR 1.72	Retrospective	[19]
O ₃	Upper respiratory tract inflammation	Increased airway reactivity	Not reported	Clinical/epidemiological	[20],[21]

The data demonstrate that both particulate and gaseous pollutants contribute to upper respiratory tract disease burden, although the strength of associations varies depending on pollutant type and clinical outcome.

CLINICAL OUTCOMES

Air pollution exposure is associated not only with disease occurrence but also with a range of clinically relevant outcomes affecting symptom burden and healthcare systems.

SYMPTOM SEVERITY AND QUALITY OF LIFE

Increased exposure to air pollutants is consistently linked to greater symptom severity and reduced quality of life in affected individuals. Exposure to ambient air pollution, particularly fine particulate matter and gaseous pollutants, has been consistently associated with increased symptoms of upper respiratory tract inflammation, including nasal congestion, rhinorrhea, and cough, which may underlie or exacerbate sinusitis in urban populations [5],[6],[22].

Current evidence shows that exposure to air pollutants is associated with increased airway inflammation and respiratory symptoms, which may contribute to upper respiratory tract disease burden [23],[20]. These clinical and mechanistic findings indicate that both short-term and long-term pollutant exposures can worsen upper respiratory tract inflammation and contribute to the symptomatic burden of sinusitis in urban settings [6],[9].

SURGICAL OUTCOMES

Higher exposure to PM2.5 was associated with an increased likelihood of revision sinus surgery, suggesting a potential relationship between air pollution and disease persistence or reduced treatment response in chronic rhinosinusitis [24].

Healthcare utilization

The impact of air pollution extends to increased healthcare utilization, reflecting both acute exacerbations and chronic disease burden. Numerous time series and clinical studies show larger relative increases in URTD-related outcomes, outpatient visits, and ED admissions for children compared with adults at similar pollution increments [14],[3].

Consistently, short-term exposure to CO, NO₂, SO₂, and O₃ has been associated with increased hospitalizations for pediatric upper respiratory tract conditions, with effect estimates varying according to disease subtype, age, and seasonality [21]. Time series and primary care data further demonstrate that short-term rises in CO, SO₂, NO₂, and particulate matter increase respiratory consultations, outpatient visits, emergency department use, and hospitalizations in both children and adults, thereby placing a substantial burden on healthcare systems, particularly during winter and high pollution episodes [15],[13],[25].

DEMOGRAPHIC AND SOCIOECONOMIC FACTORS

Susceptibility to the adverse effects of air pollution is not uniform across populations and is strongly influenced by demographic and socioeconomic factors. In particular, children and the elderly represent the most vulnerable demographic tiers within urban populations, bearing a disproportionate burden of air pollution-induced upper respiratory morbidity due to distinct biological and physiological sensitivities. Children have higher susceptibility due to prenatal and early life exposure windows, higher ventilation per body mass, immature detoxification and immune systems, and ongoing lung growth [3],[26],[27],[28]. In addition, reviews emphasize that oxidative stress-mediated injury begins prenatally and continues through childhood, contributing to increased susceptibility to upper respiratory tract diseases, impaired mucosal defense, and persistent inflammatory responses within the upper airway [23].

Furthermore, these associations are stratified by gender-based sensitivities, as gaseous pollutants typically exert a greater impact on males, whereas female populations experience a more pronounced relative risk from ambient particulates [27], [29]. Air pollution increases the risk of upper respiratory tract disease by impairing airway clearance and promoting inflammation, and in older adults, age-related declines in lung function and antioxidant defenses further increase susceptibility to these effects [30].

Older adults also represent a high-risk group, as PM_{2.5}-related emergency visits for respiratory disease and URTDs rise more in individuals aged ≥60 years than in younger adults [31]. Moreover, multicity data from 2017–2022 indicate that, over time, the profile of high-risk groups for pollution-related respiratory hospitalization has shifted from children and young adolescents towards the elderly, particularly those with comorbidities, who exhibit substantially higher odds of prolonged hospital stay and mortality following exposure [32], [15]. Finally, comorbid chronic lung or cardiovascular disease and lower socioeconomic status further compound vulnerability in both age groups [26].

EXPOSURE CHARACTERISTICS

Epidemiological evidence reveals distinct hierarchies in the strength of association between specific air pollutants and upper respiratory pathologies, with gaseous pollutants often exhibiting more potent independent effects than particulate matter in multi-pollutant models [12].

SHORT-TERM VS LONG-TERM EXPOSURE

The health effects of air pollution are influenced not only by pollutant type but also by the duration and pattern of exposure. Most studies focus on outdoor air pollution, while indoor exposure remains less well characterized in the context of respiratory health [31],[30]. These clinical and mechanistic findings highlight that both short-term and long-term pollutant exposures can worsen upper respiratory tract inflammation and contribute to the symptomatic burden of sinusitis in urban settings [6], [9]. Time series and primary care data further demonstrate that short-term rises in CO, SO₂, NO₂, and particulate matter increase respiratory consultations, outpatient visits, emergency department use, and hospitalizations in both children and adults, thereby placing a significant burden on healthcare systems, particularly during winter and high pollution episodes [15], [13], [9].

REGIONAL VARIABILITY

Geographic variation in pollutant levels and composition contributes to differences in observed health effects across populations. For example, in pediatric populations, elevated PM and NO₂ levels have been shown to drive thousands of additional hospitalizations for acute lower and upper respiratory infections, along with substantial economic costs in a single Chinese province, with pollutant-attributable costs reaching billions of CNY over a two-year period [11].

In highly polluted regions such as Kraków and Katowice, long-term monitoring studies demonstrate that concentrations of PM₁₀, PM_{2.5}, and NO₂ frequently exceed permissible levels, particularly during winter months, reflecting the dominant contribution of residential heating and traffic emissions [33],[34],[35]. In addition, health risk assessments conducted in Kraków indicate that exposure to particulate matter and associated toxic compounds, including heavy metals and PAHs, exceeds acceptable carcinogenic and non-carcinogenic risk thresholds, highlighting a significant public health burden [33],[35]. Similarly, epidemiological analyses from Katowice and other Polish cities have demonstrated significant associations between elevated concentrations of PM₁₀, PM_{2.5}, NO₂, and

benzo(a)pyrene and increased incidence of respiratory and allergic diseases, particularly in pediatric populations [34], [35]. Furthermore, national-level data indicate that although long-term trends in air pollution in Poland show gradual improvement, large urban agglomerations such as Kraków and Katowice remain disproportionately affected, with persistent spatial and seasonal variability in pollutant levels [35],[33].

DOSE-RESPONSE RELATIONSHIPS AND THRESHOLD EFFECTS

Epidemiological evidence supports the presence of dose-response relationships between air pollutant exposure and upper respiratory health outcomes [31]. At the population level, even modest relative risks translate into a substantial absolute disease burden due to the widespread and ubiquitous nature of exposure. PM_{2.5} is among the top global risk factors for death and disability, contributing to millions of deaths and more than 10⁸ disability-adjusted life years annually, with air pollution affecting nearly all regions and age groups and exerting the greatest impact in populations with the highest exposure and susceptibility [31],[36]. Importantly, harmful effects have been observed even at pollutant concentrations below current regulatory standards, and children and elderly individuals are particularly affected due to the accumulation of long-term functional impairments, including reduced lung growth, accelerated functional decline, and exacerbation of chronic disease [37],[11],[26]. Consequently, air quality improvement represents a critical preventive strategy, and evidence supports the effectiveness of emission control policies, with current reviews emphasizing the need to prioritize cleaner energy sources, reduce traffic-related emissions, and protect disadvantaged populations in order to mitigate both immediate upper respiratory tract disease morbidity and long-term noncommunicable respiratory outcomes [37],[38],[3],[26].

MECHANISMS

The biological plausibility of the link between air pollution and upper respiratory tract diseases is rooted in a multifaceted disruption of the sinonasal mucosal environment [39]. Most mechanistic evidence derives from experimental studies, including *in vitro* and animal models, which demonstrate the effects of pollutants on epithelial integrity, oxidative stress, and immune responses. In contrast, clinical and epidemiological studies provide indirect support for these mechanisms, as direct assessment of mucosal changes in human populations remains limited. Early epidemiological evidence has suggested an association between air pollution and increased prevalence of upper respiratory diseases in urban populations [8]. Air pollutants damage the respiratory mucosa primarily through oxidative stress, barrier disruption, and immune activation [6],[40]. Fine and ultrafine particles (PM_{2.5}, PM₁₀) and gaseous pollutants (NO₂, O₃, SO₂) generate reactive oxygen species that overwhelm antioxidant defences, injure epithelial cells, and trigger inflammatory cascades [4].

These processes result in tight junction disruption and impaired epithelial barrier function, increasing permeability to pathogens and allergens and promoting airway remodelling [4],[41]. In parallel, pollutants drive Th₂/Th₁₇-skewed inflammation as well as eosinophilic and neutrophilic infiltration, which are central to the pathogenesis of allergic rhinitis. Ozone and NO₂ induce airway hyperresponsiveness and bronchial inflammation, while SO₂ contributes to bronchoconstriction [12],[42],[20]. Particulate matter further promotes mucus hypersecretion, kallikrein induction, and altered gene expression in epithelial cells [41],[43].

Additionally, epigenetic changes contribute to dysregulation of immune tolerance and sustain chronic inflammatory responses. These alterations facilitate increased susceptibility to infections and exacerbate existing inflammatory conditions of the upper respiratory tract [4, 7]. Epidemiologic data also demonstrate interactions among pollutants, with NO₂ and CO increasing particulate matter penetration and jointly heightening infection risk, while combined O₃-PM_{2.5} exposures produce additive deleterious effects on inflammatory pathways [44].

DISCUSSION

This narrative review synthesizes current evidence on the association between urban air pollution and upper respiratory tract diseases, with a particular focus on chronic rhinosinusitis, allergic rhinitis, and acute sinusitis. The available literature demonstrates associations between exposure to particulate matter and gaseous pollutants and increased disease incidence, symptom severity, and healthcare utilization [1,4,10,12,22].

Importantly, the majority of included studies are observational in nature. While the consistency of findings across different populations and study designs strengthens the overall evidence base, it does not allow for definitive conclusions regarding causality. Therefore, the observed relationships should be interpreted as associative rather than causal [1,40].

Some studies suggest the presence of dose response relationships, with increasing pollutant concentrations associated with higher risk estimates. Additionally, adverse effects have been reported even at pollutant levels below current guideline thresholds, although findings remain heterogeneous [5,13,15,21].

The observed heterogeneity across studies can be explained by several factors. First, differences in study design, including cohort, case control, and time series approaches, lead to variability in effect estimates and susceptibility to bias. Second, exposure assessment methods differ substantially, ranging from fixed ambient monitoring stations to modeled exposure and, less frequently, individual level estimates, which limits comparability. Third, variation in outcome definitions, including diagnostic criteria for chronic rhinosinusitis and allergic rhinitis, contributes to inconsistent results. Fourth, population characteristics such as age distribution, baseline health status, and geographic location influence observed associations. Finally, inconsistent adjustment for confounding factors, including smoking and socioeconomic status, further contributes to variability in findings.

A key strength of the reviewed evidence is the integration of epidemiological findings with biologically plausible mechanisms, including oxidative stress, epithelial barrier dysfunction, and immune dysregulation [26,39]. Nevertheless, mechanistic data are largely derived from experimental models, and their direct translation to clinical outcomes remains limited [39].

The analysis also highlights differences between pollutants. Nitrogen dioxide appears to demonstrate stronger associations in multi pollutant models, whereas particulate matter shows more consistent, although generally moderate, effect sizes [10,30]. These findings may have implications for prioritizing environmental interventions, although further research is required.

Children and older adults emerge as particularly vulnerable populations. Increased susceptibility in children has been associated with developmental factors and higher exposure relative to body weight, while in older adults it is influenced by comorbidities and reduced physiological reserves [25,37]. Socioeconomic factors further modify risk, although they are inconsistently reported across studies [20].

Regional data remain limited. Evidence from Central and Eastern Europe, including Poland, indicates a substantial burden of exposure due to frequent exceedance of air quality standards in urban areas such as Kraków and Katowice [33,35]. Studies conducted in Polish populations report increased prevalence of upper respiratory symptoms associated with elevated particulate matter levels, supporting the relevance of global findings in this regional context [3,34].

Several limitations of the available evidence must be acknowledged. Many studies rely on ambient monitoring data, which may not accurately reflect individual exposure, particularly in indoor environments. Confounding factors such as smoking, socioeconomic status, and comorbid conditions are not consistently controlled for. Additionally, heterogeneity in disease definitions and outcome measures limits comparability across studies [20,31].

From a clinical perspective, the findings have several practical implications. In patients with chronic rhinosinusitis who demonstrate persistent symptoms despite standard therapy, assessment of environmental exposure may help explain poor disease control and support recommendations on exposure reduction [7,24]. In allergic rhinitis, periods of high pollution may exacerbate symptoms and should be considered when adjusting pharmacotherapy intensity or timing. In patients with recurrent acute sinusitis, repeated exposure to high levels of air pollution may represent a contributing factor and should be included in risk assessment. In urban populations, clinicians may consider advising patients to limit outdoor activities during peak pollution periods and to improve indoor air quality as part of a comprehensive management approach [16].

Future research should prioritize well designed longitudinal cohort studies with standardized diagnostic criteria and harmonized exposure assessment methods. Studies integrating individual level exposure data with clinical outcomes are needed to improve causal inference [9,32]. Randomized or quasi experimental intervention studies evaluating the effects of air quality improvement on upper respiratory outcomes represent a key priority. In addition, research integrating environmental exposure with genetic susceptibility and socioeconomic determinants may clarify heterogeneity of risk. Advanced analytical approaches in multi pollutant models are required to differentiate the independent effects of specific pollutants [9,32].

CONCLUSIONS

The available evidence demonstrates a consistent association between urban air pollution and chronic rhinosinusitis, supported primarily by cohort studies and large observational studies. For particulate matter, effect estimates are generally around $OR \approx 1.2$ for PM₁₀, while higher risk estimates have been reported for nitrogen dioxide in selected analyses. In allergic rhinitis, meta analyses indicate a moderate but statistically significant increase in disease prevalence and symptom severity associated with exposure to both particulate and gaseous pollutants. In contrast, evidence regarding acute sinusitis and upper respiratory tract infections remains limited, is derived mainly from time series studies and retrospective analyses, and is therefore less reliable.

Short term exposure to pollutants, including PM_{2.5}, NO₂, SO₂, and CO, is associated with increased outpatient visits,

hospitalizations, and symptom exacerbations. Long term exposure is more consistently associated with disease persistence and greater severity in chronic rhinosinusitis.

The main sources of heterogeneity include differences in exposure assessment, variability in diagnostic criteria, incomplete control of confounding factors, and differences in study design. Exposure misclassification and heterogeneity in outcome definitions appear to contribute most substantially to variability in effect estimates.

From a clinical perspective, environmental exposure may be considered an additional factor influencing the course of upper respiratory tract diseases and may be taken into account when interpreting the clinical course within existing management frameworks. A possible contribution of pollution may be considered when persistent symptoms despite standard therapy, increased frequency of exacerbations, increased healthcare utilization, and temporal association with pollution peaks are present.

In chronic rhinosinusitis, these features are associated with a more severe or persistent disease course and may be considered in clinical decision making within existing recommendations. In allergic rhinitis, pollution may act as an additional trigger contributing to symptom worsening within stepwise therapeutic approaches. In recurrent acute sinusitis, the environmental factor may be considered as a risk modifying parameter, although current evidence does not support modification of standard therapy.

Reduction of outdoor exposure during peak pollution periods and improvement of indoor air quality may be considered potentially beneficial measures, although their impact on clinical outcomes requires further investigation. Symptoms should be reassessed with consideration of environmental exposure.

Children and older adults appear to be the most vulnerable groups, as reflected by increased symptom frequency and healthcare utilization during short term exposure. Additional vulnerability is observed in patients with chronic upper respiratory tract diseases and in individuals with adverse socioeconomic conditions.

The biological plausibility of the observed associations is supported by mechanisms involving oxidative stress, epithelial barrier disruption, and immune dysregulation, which may explain persistent inflammation and reduced treatment effectiveness.

Overall, the strongest evidence is available for chronic rhinosinusitis, moderate for allergic rhinitis, and limited for acute sinusitis. The most reliable data derive from cohort studies and meta analyses, whereas time series and retrospective analyses are more susceptible to systematic biases.

Future research should prioritize prospective cohort studies with standardized diagnostic criteria and interventional studies evaluating the impact of improved air quality on clinical outcomes.

DISCLOSURE

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CONFLICT OF INTEREST

Authors declare no conflicts of interest.

REFERENCES

1. Chen SW, Lin HJ, Tsai SC, Lin CL, Hsu CY, Hsieh TL, et al. Exposure to Air Pollutants Increases the Risk of Chronic Rhinosinusitis in Taiwan Residents. *Toxics*. 2022;10(4). DOI: <https://doi.org/10.3390/toxics10040173>
2. Iqbal M, Khan MH, Rehman HU, Hussain A, Ahmad J, Ayaz M. THE IMPACTS OF AIR POLLUTANTS ON THE DEVELOPMENT AND PROGRESSION OF EAR, NOSE, AND THROAT CONDITIONS. *Journal of Population Therapeutics & Clinical Pharmacology*. 2024. DOI: <https://doi.org/10.53555/jptcp.v31i3.5171>
3. Ratajczak A, Badyda A, Czechowski PO, Czarnecki A, Dubrawski M, Feleszko W. Air Pollution Increases the Incidence of Upper Respiratory Tract Symptoms among Polish Children. *J Clin Med*. 2021;10(10). DOI: <https://doi.org/10.3390/jcm10102150>
4. Rosario CS, Urrutia-Pereira M, Murrieta-Aguttes M, D'Amato G, Chong-Silva DC, Godoi RHM, et al. Air pollution and rhinitis. *Front Allergy*. 2024;5:1387525. DOI: <https://doi.org/10.3389/falgy.2024.1387525>
5. Lu M, Ding S, Wang J, Liu Y, An Z, Li J, et al. Acute effect of ambient air pollution on hospital outpatient cases of chronic sinusitis in Xinxiang, China. *Ecotoxicol Environ Saf*. 2020;202:110923. DOI: <https://doi.org/10.1016/j.ecoenv.2020.110923>
6. Leland EM, Zhang Z, Kelly KM, Ramanathan M, Jr. Role of Environmental Air Pollution in Chronic Rhinosinusitis. *Curr Allergy Asthma Rep*. 2021;21(8):42. DOI: <https://doi.org/10.1007/s11882-021-01019-6>
7. Peeters S, Wang C, Bijlens EM, Bullens DMA, Fokkens WJ, Bachert C, et al. Association between outdoor air pollution and chronic rhinosinusitis patient reported outcomes. *Environ Health*. 2022;21(1):134. DOI: <https://doi.org/10.1186/s12940-022-00948-7>
8. Paul R, Portney JM. Urban air quality and chronic respiratory disease. *Regional Science and Urban Economics*. 1990. DOI: [https://doi.org/10.1016/0166-0462\(90\)90019-Y](https://doi.org/10.1016/0166-0462(90)90019-Y)
9. Zhou Q, Ma J, Biswal S, Rowan NR, London NR, Riley CA, et al. Air pollution, genetic factors, and chronic rhinosinusitis: A prospective study in the UK Biobank. *Sci Total Environ*. 2024;940:173526. DOI: <https://doi.org/10.1016/j.scitotenv.2024.173526>
10. Lee YG, Lee PH, Choi SM, An MH, Jang AS. Effects of Air Pollutants on Airway Diseases. *Int J Environ Res Public Health*. 2021;18(18). DOI: <https://doi.org/10.3390/ijerph18189905>
11. He Y, Jiang W, Gao X, Lin C, Li J, Yang L. Short-term effects and economic burden of air pollutants on acute lower respiratory tract infections in children in Southwest China: a time-series study. *Environ Health*. 2023;22(1):6. DOI: <https://doi.org/10.1186/s12940-023-00962-3>
12. Zhang ZQ, Li JY, Guo Q, Li YL, Bao YW, Song YQ, et al. Association between air pollution and allergic upper respiratory diseases: a meta-analysis. *Eur Respir Rev*. 2025;34(176). DOI: <https://doi.org/10.1183/16000617.0266-2024>
13. Huang JY, Feng W, Sang GX, McDonald S, He TF, Lin Y. Association between short-term exposure to ambient air pollutants and the risk of hospital visits for acute upper respiratory tract infections among adults: a time-series study in Ningbo, China. *BMC Public Health*. 2024;24(1):1555. DOI: <https://doi.org/10.1186/s12889-024-19030-7>
14. Ma Y, Yue L, Liu J, He X, Li L, Niu J, et al. Association of air pollution with outpatient visits for respiratory diseases of children in an ex-heavily polluted Northwestern city, China. *BMC Public Health*. 2020;20(1):816. DOI: <https://doi.org/10.1186/s12889-020-08933-w>
15. Xu Q, Li X, Wang S, Wang C, Huang F, Gao Q, et al. Fine Particulate Air Pollution and Hospital Emergency Room Visits for Respiratory Disease in Urban Areas in Beijing, China, in 2013. *PLoS One*. 2016;11(4):e0153099. DOI: <https://doi.org/10.1371/journal.pone.0153099>
16. Eguiluz-Gracia I, Mathioudakis AG, Bartel S, Vijverberg SJH, Fuertes E, Comberati P, et al. The need for clean air: The way air pollution and climate change affect allergic rhinitis and asthma. *Allergy*. 2020;75(9):2170-84. DOI: <https://doi.org/10.1111/all.14177>
17. Wang Y, Zhong W, Wang Z, Cui N, Liu C, Yang J. Effects of meteorological factors and air pollution on the number of allergic rhinitis outpatient visits in Changchun city, China. *Sci Rep*. 2025;15(1):32406. DOI: <https://doi.org/10.1038/s41598-025-16265-1>
18. Willson TJ, Lospinoso J, Weitzel EK, McMains KC. Effect of environmental factors on Internet searches related

- to sinusitis. *Laryngoscope*. 2015;125(11):2447-50. DOI: <https://doi.org/10.1002/lary.25420>
19. Wawryk-Gawda E, Miga-Orczykowska N, Matusiak J, Mandziuk D, Gizewska K, Opoka-Winiarska V. Air pollution exposure and the burden of pediatric upper respiratory tract infections in emergency departments: a retrospective time-series study. *Eur J Pediatr*. 2025;184(12):753. DOI: <https://doi.org/10.1007/s00431-025-06572-0>
 20. Bala GP, Rajnoveanu RM, Tudorache E, Motisan R, Oancea C. Air pollution exposure-the (in)visible risk factor for respiratory diseases. *Environ Sci Pollut Res Int*. 2021;28(16):19615-28. DOI: <https://doi.org/10.1007/s11356-021-13208-x>
 21. Xu H, Wang X, Tian Y, Tian J, Zeng Y, Guo Y, et al. Short-term exposure to gaseous air pollutants and daily hospitalizations for acute upper and lower respiratory infections among children from 25 cities in China. *Environ Res*. 2022;212(Pt D):113493. DOI: <https://doi.org/10.1016/j.envres.2022.113493>
 22. Liu T, Liu Y, Su Y, Hao J, Liu S. Air pollution and upper respiratory diseases: an examination among medically insured populations in Wuhan, China. *Int J Biometeorol*. 2024;68(6):1123-32. DOI: <https://doi.org/10.1007/s00484-024-02651-3>
 23. Kurt OK, Zhang J, Pinkerton KE. Pulmonary health effects of air pollution. *Curr Opin Pulm Med*. 2016;22(2):138-43. DOI: <https://doi.org/10.1097/MCP.0000000000000248>
 24. Hagedorn R, Tullis B, Nguyen C, Stockard R, Mace JC, Ramakrishnan VR, et al. Does air pollutant exposure impact disease severity or outcomes in chronic rhinosinusitis? *Int Forum Allergy Rhinol*. 2024;14(4):755-64. DOI: <https://doi.org/10.1002/alr.23250>
 25. Fonderson MS, van Meel ER, Bindels P, Bohnen A, Burdorf A, de Schepper E. Air pollution and childhood respiratory consultations in primary care: a systematic review. *Arch Dis Child*. 2024;109(4):297-303. DOI: <https://doi.org/10.1136/archdischild-2023-326368>
 26. Dondi A, Carbone C, Manieri E, Zama D, Del Bono C, Betti L, et al. Outdoor Air Pollution and Childhood Respiratory Disease: The Role of Oxidative Stress. *Int J Mol Sci*. 2023;24(5). DOI: <https://doi.org/10.3390/ijms24054345>
 27. Huang ZH, Liu XY, Zhao T, Jiao KZ, Ma XX, Ren Z, et al. Short-term effects of air pollution on respiratory diseases among young children in Wuhan city, China. *World J Pediatr*. 2022;18(5):333-42. DOI: <https://doi.org/10.1007/s12519-022-00533-5>
 28. Esposito S, Fainardi V, Titolo A, Lazzara A, Menzella M, Campana B, et al. How air pollution fuels respiratory infections in children: current insights. *Front Public Health*. 2025;13:1567206. DOI: <https://doi.org/10.1007/s12519-022-00533-5>
 29. Li J, Feng C, Ma X, Wu D. Impact of the urban atmospheric environment on otolaryngologic disease outpatient visits in Lanzhou, China. *Sci Rep*. 2025;15(1):21556. DOI: <https://doi.org/10.1038/s41598-025-07352-4>
 30. Wallbanks S, Griffiths B, Thomas M, Price OJ, Sylvester KP. Impact of environmental air pollution on respiratory health and function. *Physiol Rep*. 2024;12(16):e70006. DOI: <https://doi.org/10.14814/phy2.70006>
 31. Schraufnagel DE, Balmes JR, Cowl CT, De Matteis S, Jung SH, Mortimer K, et al. Air Pollution and Noncommunicable Diseases: A Review by the Forum of International Respiratory Societies' Environmental Committee, Part 1: The Damaging Effects of Air Pollution. *Chest*. 2019;155(2):409-16. DOI: <https://doi.org/10.1016/j.chest.2018.10.042>
 32. Jiang S, Tang L, Lou Z, Wang H, Huang L, Zhao W, et al. The changing health effects of air pollution exposure for respiratory diseases: a multicity study during 2017-2022. *Environ Health*. 2024;23(1):36. DOI: <https://doi.org/10.1186/s12940-024-01083-1>
 33. Traczyk P, Gruszecka-Kosowska A. The Condition of Air Pollution in Krakow, Poland, in 2005-2020, with Health Risk Assessment. *Int J Environ Res Public Health*. 2020;17(17). DOI: <https://doi.org/10.3390/ijerph17176063>
 34. Góra DJ, Kupiec JM. Relationship Between Air Pollution and the Incidence of Selected Disease Among Children and Adolescents in the Years 2017-2023 in Selected Cities in Poland. *Civil and Environmental Engineering Reports*. 2024;34(4):246-71. DOI: <https://doi.org/10.59440/ceer/194873>
 35. Jaroń A, Borucka A, Ślusarczyk M. Long-Term Trends in Air Pollution in Poland on Selected Examples—A Spatial and Temporal Analysis of PM10 Concentrations. *Applied Sciences*. 2025;15(23). DOI: <https://doi.org/10.3390/app152312379>
 36. Schraufnagel DE, Balmes JR, Cowl CT, De Matteis S, Jung SH, Mortimer K, et al. Air Pollution and Noncommunicable Diseases: A Review by the Forum of International Respiratory Societies' Environmental Committee, Part 2: Air Pollution and Organ Systems. *Chest*. 2019;155(2):417-26. DOI: <https://doi.org/10.1016/j.chest.2018.10.041>
 37. Mocelin HT, Fischer GB, Bush A. Adverse early-life environmental exposures and their repercussions on adult

- respiratory health. *J Pediatr (Rio J)*. 2022;98 Suppl 1(Suppl 1):S86-S95. DOI: <https://doi.org/10.1016/j.jpmed.2021.11.005>
38. Domingo KN, Gabaldon KL, Hussari MN, Yap JM, Valmadrid LC, Robinson K, et al. Impact of climate change on paediatric respiratory health: pollutants and aeroallergens. *Eur Respir Rev*. 2024;33(172). DOI: <https://doi.org/10.1183/16000617.0249-2023>
39. Hamanaka RB, Mutlu GM. Particulate matter air pollution: effects on the respiratory system. *J Clin Invest*. 2025;135(17). DOI: <https://doi.org/10.1172/JCI194312>
40. Leland EM, Vohra V, Seal SM, Zhang Z, Ramanathan Jr M. Environmental air pollution and chronic rhinosinusitis: A systematic review. *Laryngoscope Investig Otolaryngol*. 2022. DOI: <https://doi.org/10.1002/lio2.774>
41. Patel TR, Tajudeen BA, Brown H, Gattuso P, LoSavio P, Papagiannopoulos P, et al. Association of Air Pollutant Exposure and Sinonasal Histopathology Findings in Chronic Rhinosinusitis. *Am J Rhinol Allergy*. 2021;35(6):761-7. DOI: <https://doi.org/10.1177/1945892421993655>
42. Hung SH, Cheng YF, Lin HC, Chen CS. Seasonality in the incidence of acute sinusitis, air pollutant levels, and climate. *Rhinology*. 2025;63(5):576-83. DOI: <https://doi.org/10.4193/Rhin25.054>
43. Altman MC, Kattan M, O'Connor GT, Murphy RC, Whalen E, LeBeau P, et al. Associations between outdoor air pollutants and non-viral asthma exacerbations and airway inflammatory responses in children and adolescents living in urban areas in the USA: a retrospective secondary analysis. *Lancet Planet Health*. 2023;7(1):e33-e44. DOI: [https://doi.org/10.1016/S2542-5196\(22\)00302-3](https://doi.org/10.1016/S2542-5196(22)00302-3)
44. Park M, Lee JS, Park MK. The Effects of Air Pollutants on the Prevalence of Common Ear, Nose, and Throat Diseases in South Korea: A National Population-Based Study. *Clin Exp Otorhinolaryngol*. 2019;12(3):294-300. DOI: <https://doi.org/10.21053/ceo.2018.00612>

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