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IMPACT OF ENVIRONMENTAL AIR POLLUTION ON ALLERGIC RHINITIS SEVERITY AND QUALITY OF LIFE IN ADULTS: A NARRATIVE REVIEW

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ABSTRACT

Air pollution is recognized as one of the leading environmental determinants of human health. It has been associated with a growing burden of respiratory diseases worldwide. Allergic rhinitis (AR), a chronic inflammatory disorder of the upper airways, may be susceptible to the effects of environmental pollutants. This narrative review aimed to summarize current evidence regarding the impact of air pollution on allergic rhinitis severity, disease control, and quality of life in adults.

A literature search was conducted using the PubMed database. Relevant publications were identified using combinations of the keywords with priority given to recent systematic reviews, meta-analyses, observational studies, clinical investigations, and international clinical guidelines.

The reviewed evidence consistently demonstrated positive associations between exposure to ambient air pollutants and allergic rhinitis outcomes. Particulate matter (PM2.5 and PM10), nitrogen dioxide (NO_2), ozone (O_3), and sulfur dioxide (SO_2) were most frequently associated with increased symptom severity, poorer disease control, and reduced quality of life. Particulate matter showed the strongest and most consistent relationship with allergic rhinitis burden. Proposed biological mechanisms include oxidative stress, epithelial barrier dysfunction, chronic inflammation, and immune dysregulation.

In conclusion, air pollution represents an important and potentially modifiable determinant of allergic rhinitis severity and quality of life. Improving air quality and reducing individual exposure to environmental pollutants may contribute to better disease control and reduced burden of allergic respiratory diseases, highlighting the importance of both clinical and public health interventions.

KEYWORDS

Allergic Rhinitis; Air Pollution; Particulate Matter; Oxidative Stress; Quality of Life; Environmental Exposure

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1. Introduction

1.1 Air pollution

Air pollution is one of the most important environmental risk factors for health and contributes to a wide range of health problems [14, 26]. According to the World Health Organization (WHO), millions of people are exposed daily to harmful concentrations of airborne pollutants that contribute to respiratory and cardiovascular diseases [25, 26].

Air pollution is inextricably associated with human activity. Major anthropogenic sources include road traffic, industrial production, energy generation and residential heating. Traffic-related air pollution is considered particularly relevant for respiratory diseases because vehicle emissions contain particulate matter, nitrogen oxides, volatile organic compounds, and secondary pollutants formed through atmospheric reactions.

It is predicted that climate change may worsen air quality through increased global temperatures, altered atmospheric circulation patterns, more frequent wildfires, and longer pollen seasons.

The pollutants under review include particulate matter with a diameter of less than 2,5 μm ($PM_{2.5}$), less than 10 μm (PM_{10}), ozone (O_3), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2). PM is a complex mixture with components of different chemical and physical characteristics. Common components of particulate matter (PM) are liquid and solid particles suspended in the air like elemental carbon and organic carbon molecules, such as polyaromatic hydrocarbons (PAHs), nitrates, sulfates and various metals [7, 27]. Different characteristics of PM may be relevant to different health effects [25].

Tropospheric ozone (O_3), sulfur dioxide (SO_2) and nitrogen dioxide gas (NO_2) are strong oxidants [25]. Overproduction of strong oxidants are the primary drivers of oxidative stress.

The respiratory system is a primary target for pollutants. Inhaling these pollutants leads to inflammation, oxidative stress, and impaired lung function [6].

Increasing evidence suggests that environmental pollution may also influence the occurrence and severity of allergic diseases, including allergic rhinitis [1].

1.2 Allergic rhinitis

Allergic rhinitis (AR) is one of the most prevalent allergic diseases [1]. It affects up to 30% of the European population and up to 60 million people in the United States, including children, adolescents and adults [3, 24]. The prevalence of allergic rhinitis is likely to increase. Allergic rhinitis is an atopic disease associated with inflammation, and characterized by symptoms of nasal congestion, rhinorrhea, sneezing - especially paroxysmal, postnasal drip, ocular symptoms (such as itch, redness or tearing), nasal itch and obstruction. Patient presenting two or more mentioned above nasal symptoms may be diagnosed to allergic rhinitis [4, 24].

AR is primarily an IgE-mediates (immunoglobulin E) inflammatory disease triggered by exposure to an allergen.

Many recent studies found the link between pollution and the development of AR [4, 15]. Rhinitis symptom control is associated with exposure to environmental triggers (e.g. aeroallergens, pollutants, and irritants), not only allergens [13].

Classically, seasonal AR was associated with outdoor allergens like pollen, perennial AR with indoor year-round exposure to allergens such as dust mites or pet dander, and episodic AR with temporary allergen exposures not normally occurring in the patient's environment, such as visiting a home with pets. However, climate change, air pollution and polysensitization may change these classifications [2, 3, 21].

According to current knowledge allergic rhinitis may have a mild, moderate, or severe clinical course. The criteria for this classification are the impact of the disease on daily activities, sports, attendance at school or work, sleep, and the patient's reported need for therapy [5]. Both classifications can be intertwined (Figure 1).

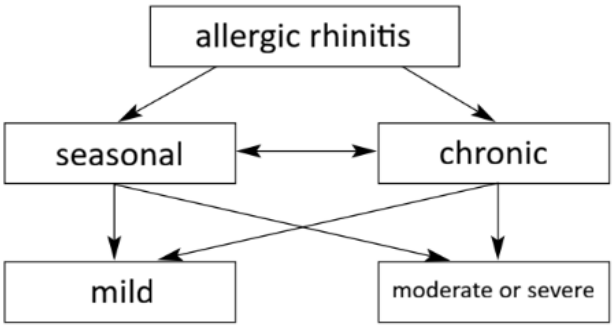

Fig. 1. *Classification of allergic rhinitis according to ARIA (adapted from Emeryk et al. [5]).*

2. Materials and Methods

This study was designed as a narrative review of the literature. The aim of the study is to summarize current evidence regarding the relationship between exposure to air pollution and the severity of allergic rhinitis in adults, with emphasis on the biological mechanisms involved and the public health implications of these associations. To achieve this, the authors conducted a review of relevant and current articles from the PubMed database.

The search strategy included combinations of keywords such as: "allergic rhinitis", "hay fever", "severity", "control", "air pollution", "PM2.5", "PM10", "NO2", "ozone". To increase accuracy of the results, logical operators "AND" and "OR" were used.

Priority was given to recent studies, systematic reviews, meta-analyses and clinical investigations. Studies investigating impact of air pollution on health, especially the respiratory system and atopic diseases were searched for.

The analysis excluded non-peer-reviewed publications, case studies, conference abstracts without full text. Studies focusing on pediatric population or publication not available in Polish or English were also excluded.

The selection process proceeded in several stages. First, titles and abstracts were screened for thematic relevance, and then the full text of the selected studies were analyzed. The collected material was grouped according to thematic categories.

Clinical guidelines for allergic rhinitis were also reviewed: American Academy of Allergy, Asthma & Immunology (AAAAI), Allergic Rhinitis and its Impact on Asthma (ARIA). In total, 27 sources were included in the review, with 26 published no later than 2020.

The selected literature was reviewed and synthesized narratively according to major thematic areas.

Although no risk-of-bias tool was used, the methodological quality of the included studies was critically analyzed by the authors.

Due to the nature of narrative review, formal systematic procedures, as PRISMA, were not used, which is a potential limitation of the study.

3. Air Pollution and Allergic Rhinitis

3.1 Epidemiological Evidence

Most studies suggest that exposure to air pollution is associated with an increased burden of allergic rhinitis (AR) and other allergic diseases. Multiple epidemiological studies have demonstrated positive associations between exposure to ambient pollutants and the prevalence, severity, and persistence of allergic respiratory diseases. Exposure to air pollution, particularly particulate matter and traffic-related pollutants, was significantly associated with an increased risk of allergic rhinitis. $PM_{2.5}$ and NO_2 demonstrated the most consistent associations with allergic airway disease [1, 8, 10, 18].

Geographic location, degree of urbanization, and socioeconomic factors were identified as potential modifiers of this relationship [1, 15].

3.2 Effects of Particulate Matter on Allergic Rhinitis

Particulate matter appears to be the most extensively studied pollutant in relation to allergic rhinitis. Several investigations have demonstrated that both $PM_{2.5}$ and PM_{10} are associated with increased symptom severity, including nasal congestion, rhinorrhea, sneezing, and nasal itching.

Some studies reported that long-term exposure to $PM_{2.5}$ was associated with the presence of rhinitis in older adults and that inflammatory cytokine profiles partially mediated this relationship. Similarly, there was observed a positive correlation between PM_{10} concentrations and both the severity and duration of rhinitis symptoms [7, 8, 9, 10, 20].

Additional support for the role of particulate matter comes from intervention studies. Park et al. found that the use of high-efficiency particulate air (HEPA) filters significantly reduced indoor $PM_{2.5}$ concentrations and was associated with decreased medication requirements among patients with house dust mite-induced allergic rhinitis [12].

3.3 Oxidative Stress and Biological Mechanisms

Several studies have explored the biological mechanisms linking air pollution to allergic rhinitis. These mechanisms involve multiple pathways associated with oxidative stress, immune dysregulation, epithelial barrier dysfunction, and chronic inflammation. Oxidative stress is considered one of the principal pathways through which pollutants exert adverse effects on the respiratory tract. It also may stimulate the expression of antioxidant genes and recruitment of inflammatory cells to the nasal mucosa [2, 8, 10, 11].

Air pollutants, particularly particulate matter, ozone, and nitrogen dioxide, are capable of generating reactive oxygen species (ROS) within the airway epithelium. Short-term exposure to mixtures of air pollutants is associated with increased oxidative stress markers, including elevated malondialdehyde (MDA) levels, a biomarker of lipid peroxidation and oxidative damage, and reduced superoxide dismutase (SOD) activity - one of the major endogenous antioxidant enzymes responsible for neutralizing reactive oxygen species. Patients exposed to higher pollutant concentrations experienced more severe nasal symptoms and poorer quality of life, suggesting an association between pollutant-induced oxidative stress and disease severity [22].

Population-based studies have demonstrated that long-term exposure to fine particulate matter and markers of airway inflammation (specific inflammatory cytokine profiles) in older adults suggest that pollution-related inflammatory processes may contribute not only to lower respiratory diseases but also to upper airway conditions such as allergic rhinitis [10, 17].

Particulate matter, ozone, and nitrogen dioxide are known to generate reactive oxygen species within the respiratory epithelium, leading to epithelial barrier dysfunction, inflammation, and enhanced allergic

sensitization. Pollutants may stimulate epithelial cells, macrophages, and dendritic cells to release pro-inflammatory mediators, resulting in the recruitment of inflammatory cells [8, 10]. The nasal epithelium is the first line of defense against inhaled pollutants, making it particularly vulnerable to oxidative injury. Chronic exposure may contribute to persistent airway inflammation and increased susceptibility to respiratory symptoms.

3.4 Air pollution and aeroallergen interactions

Recent studies have highlighted the interaction between atmospheric pollution and aeroallergens. During pollen seasons, exposure to particulate matter (especially $PM_{2,5}$) and gaseous pollutants may amplify allergic responses and exacerbate respiratory symptoms in sensitized individuals. Air pollutants can modify pollen content, morphology, immunomodulatory properties, and immunogenicity. They have been linked to elevated pollen allergenic proteins potency. Furthermore, air pollutants can cause negative health effects even in individuals without diagnosed allergies [13, 19, 21].

Moreover, because of global warming, pollen season have become longer and more intense. Vegetation patterns, plant physiology and concentration of pollens have changed. This interaction may become increasingly relevant in the context of climate change and prolonged pollen seasons. Finding suggest that environmental factors play an important role in allergic rhinitis control [21, 23].

3.5 Disease Control, Quality of Life, and Public Health Implications

Beyond its effects on symptom severity, air pollution may substantially influence disease control and quality of life among individuals with allergic rhinitis. Increased pollutant exposure has been associated with greater healthcare utilization, more frequent outpatient visits, and increased medication use [22, 23].

Li et al. reported that concentrations of $PM_{2.5}$, PM_{10}, NO_2, SO_2, and CO (carbon monoxide) were significantly associated with increased outpatient visits for otolaryngologic diseases, including allergic rhinitis. The strongest effects were observed several days after pollutant exposure, suggesting cumulative impacts on respiratory health [16].

Air pollution may also affect daily functioning and overall well-being. Studies indicate that individuals exposed to higher pollution levels report poorer health-related quality of life, increased symptom burden, and greater limitations in everyday activities. These findings emphasize that allergic rhinitis should be considered not only a clinical condition but also a public health concern influenced by environmental factors [6, 25, 26].

Given increasing urbanization and ongoing environmental challenges, reducing exposure to harmful air pollutants may represent an important strategy for improving respiratory health outcomes and reducing the societal burden associated with allergic diseases.

4. Discussion

Our study summarizes the relationship between air pollution exposure and allergic rhinitis severity in adults. The findings indicate that exposure to ambient air pollutants as particularly particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and ozone (O_3), is associated with increased symptom severity, poorer disease control, and reduced quality of life among individuals with allergic rhinitis.

Among the pollutants evaluated, particulate matter demonstrated the most consistent association with allergic rhinitis outcomes. Several studies reported positive correlations between $PM_{2.5}$ and PM_{10} concentrations and the severity, duration, and persistence of rhinitis symptoms [7, 9, 10, 20].

The biological mechanisms underlying these associations are probably complex and multifactorial. According to current knowledge, air pollutants can induce oxidative stress through the generation of reactive oxygen species, resulting in epithelial barrier dysfunction, local inflammation, and increased mucosal permeability [8, 10]. Furthermore, chronic exposure to pollutants may promote the release of pro-inflammatory cytokines and contribute to persistent airway inflammation. The observed increases in oxidative stress biomarkers and reductions in antioxidant activity among patients exposed to pollutant mixtures provide additional evidence supporting these mechanisms [22].

Another important finding is the interaction between air pollution and aeroallergens. Several studies suggest that pollutants may amplify the effects of pollen exposure, resulting in more severe respiratory symptoms during pollen seasons. Consequently, environmental factors should be considered alongside traditional allergen avoidance strategies in the management of allergic rhinitis [13, 19, 20, 21, 23].

The subsequent challenge is urbanization. Increasing population density in large agglomerations, expanding transportation networks, and industrial development contribute to elevated pollution levels in many

regions, especially in developing countries. Individuals residing in urban environments are therefore more likely to experience chronic exposure to traffic-related pollutants and other airborne contaminants associated with respiratory disease burden [26]. As urban populations continue to grow, the impact of environmental pollution on allergic diseases may increase significantly.

Environmental exposure assessment should be considered an important component of patient medical evaluation [2,3]. Consequently, clinicians should take more interest with supplementing the medical history with information about environmental conditions, occupational exposures, residential proximity to major roads or industrial facilities, and indoor air quality when assessing patients with allergic rhinitis. Identification of environmental risk factors may enable to implement more individualized management strategies. These individualized strategies may lead to a significant reduction of medication dosage taken by patient.

Patient education programs should include recommendations about monitoring local air quality indices, limiting outdoor activities during periods of poor air quality, reducing exposure during peak traffic hours, and utilizing air purification systems in indoor environments. Although these interventions do not fully replace pharmacological treatment and proper specialists care, they may contribute to improved symptom control and reduced disease burden [2].

In present times, modern approaches to managing allergic rhinitis are based on the concept of environmental control. The International Consensus statement on Allergy and Rhinology (ICAR) reiterates the significance of the environmental factors in the development of the allergic illness and recommends a comprehensive treatment plan, which comprises pharmacological interventions, avoidance of allergens, and environmental interventions where needed [2]. Along the same lines, the Rhinitis 2020 practice parameter emphasizes the fact that environmental factors contribute to the severity of symptoms and encourages the inclusion of exposure reduction measures in patient education [3].

We cannot ignore public health implications. Allergic rhinitis is associated with impaired sleep quality, reduced work and school productivity, and diminished quality of life. Air pollution may further exacerbate these outcomes by increasing symptom burden and healthcare utilization. From a public health perspective, improving air quality has become an important strategy for reducing the burden of respiratory diseases, including rhinitis and improving the health of the population [25, 26].

Public health interventions focused on improving air quality have the potential to produce more benefits than to allergic rhinitis alone. Strategies such as promotion of renewable energy sources, cleaner transportation systems, stricter industrial emission standards, and improved urban planning may reduce exposure to harmful pollutants and improve respiratory health at all the population [25,26]. Such measures may also contribute to reductions in healthcare expenditures and productivity losses associated with chronic respiratory diseases.

Finally, increasing attention among healthcare professionals, politicians, and the general public remains essential. Allergic rhinitis is often perceived as a relatively mild condition despite its substantial impact on daily functioning and quality of life. However, we must not forget that air pollution also has a significant impact on other diseases, such as cardiovascular and respiratory diseases, and are estimated to be responsible for approximately 6.7 million attributable deaths each year [26]. Recognition of the contribution of environmental pollution to disease burden may encourage greater investment in prevention strategies and support policies aimed at improving air quality.

The findings of this review are not without limitations. First, most available studies were observational in nature, limiting the ability to establish causal relationships. Second, considerable heterogeneity existed in exposure assessment methods, pollutant measurements, study populations, and outcome definitions. Third, many studies relied on regional air quality monitoring data, which may not accurately reflect individual exposure levels. Finally, publication bias and residual confounding cannot be excluded.

For all these limitations, the available evidence consistently suggests that air pollution contributes to the severity and burden of allergic rhinitis. Future research should focus on large prospective cohort studies using standardized exposure assessment methods and validated measures of disease control and quality of life. Additional investigation is also needed to evaluate the effectiveness of environmental interventions, including air quality improvement policies and individual exposure reduction strategies.

5. Conclusions

Based on the conducted literature review, it can be concluded that air pollutants, particularly particulate matter (PM2.5 and PM10), nitrogen dioxide (NO_2), ozone (O_3), and sulfur dioxide (SO_2) are a major contributor to both quantity and severity of episodes of allergic rhinitis. Among these pollutants, particulate matter (PM) appears to show the most consistent relationship with allergic rhinitis severity, symptom persistence, and impaired disease control. Furthermore, air pollutants can cause negative health effects even in individuals without diagnosed allergies.

Air pollution should be recognized as a significant and potentially modifiable determinant of allergic rhinitis severity and quality of life. Given the growing burden of environmental pollution worldwide, improving air quality should be considered an important public health strategy to reduce the impact of allergic respiratory diseases. Reducing environmental pollutant exposure may not only alleviate the burden of allergic rhinitis but also contribute to broader improvements in respiratory health and population well-being.

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REFERENCES

1. Li, S., Wu, W., Wang, G., Zhang, X., Guo, Q., Wang, B., Cao, S., Yan, M., Pan, X., Xue, T., Gong, J., & Duan, X. (2022). Association between exposure to air pollution and risk of allergic rhinitis: A systematic review and meta-analysis. *Environmental Research, 205*, 112472. https://doi.org/10.1016/j.envres.2021.112472
2. Wise, S. K., Damask, C., Roland, L. T., Ebert, C., Levy, J. M., Lin, S., Luong, A., Rodriguez, K., Sedaghat, A. R., Toskala, E., Villwock, J., Abdullah, B., Akdis, C., Alt, J. A., Ansotegui, I. J., Azar, A., Baroody, F., Benninger, M. S., Bernstein, J., . . . Zhang, L. (2023). International consensus statement on allergy and rhinology: Allergic rhinitis—2023. *International Forum of Allergy & Rhinology, 13*(4), 293–859. https://doi.org/10.1002/alr.23090
3. Dykewicz, M. S., Wallace, D. V., Amrol, D. J., Baroody, F. M., Bernstein, J. A., Craig, T. J., Dinakar, C., Ellis, A. K., Finegold, I., Golden, D. B. K., Greenhawt, M. J., Hagan, J. B., Horner, C. C., Khan, D. A., Lang, D. M., Larenas-Linnemann, D. E. S., Lieberman, J. A., Meltzer, E. O., Oppenheimer, J. J., . . . Wang, J. (2020). Rhinitis 2020: A practice parameter update. *Journal of Allergy and Clinical Immunology, 146*(4), 721–767. https://doi.org/10.1016/j.jaci.2020.07.007
4. Akhouri, S., & House, S. A. (2023). Allergic rhinitis. In *StatPearls*. StatPearls Publishing. https://www.ncbi.nlm.nih.gov/books/NBK538186/
5. Emeryk, A., Bartkowiak-Emeryk, M., & Kowalska, M. (2012). Definition, classification and epidemiology of allergic rhinitis. *Postępy Dermatologii i Alergologii/Advances in Dermatology and Allergology Supplement*, 1–5.
6. de Bont, J., Jaganathan, S., Dahlquist, M., Persson, Å., Stafoggia, M., & Ljungman, P. (2022). Ambient air pollution and cardiovascular diseases: An umbrella review of systematic reviews and meta-analyses. *Journal of Internal Medicine, 291*(6), 779–800. https://doi.org/10.1111/joim.13467
7. Hamanaka, R. B., & Mutlu, G. M. (2025). Particulate matter air pollution: Effects on the respiratory system. *Journal of Clinical Investigation, 135*(17), e194312. https://doi.org/10.1172/JCI194312
8. Xu, X., Liu, X., Li, J., Deng, X., Dai, T., Ji, Q., Xiong, D., & Xie, H. (2023). Environmental risk factors, protective factors, and biomarkers for allergic rhinitis: A systematic umbrella review of the evidence. *Clinical Reviews in Allergy & Immunology, 65*(2), 188–205. https://doi.org/10.1007/s12016-023-08964-2
9. Jia, X., Shen, Z., Liu, R., et al. (2022). Association of fine particulate matter to allergic rhinitis: A systematic review and meta-analysis. *European Journal of Inflammation, 20*. https://doi.org/10.1177/1721727X221089839
10. Scussiatto, H. O., Wroblewski, K. E., Pagel, K. L., Schumm, L. P., McClintock, M. K., Ramanathan, M., Jr., Suh, H. H., & Pinto, J. M. (2024). Air pollution exposure is associated with rhinitis in older US adults via specific immune mechanisms. *International Forum of Allergy & Rhinology, 14*(1), 68–77. https://doi.org/10.1002/alr.23225
11. Tagliaferro, S., Pirona, F., Fasola, S., Stanisci, I., Sarno, G., Baldacci, S., Gariazzo, C., Licitra, G., Moro, A., Silibello, C., Stafoggia, M., Viegi, G., & Maio, S. (2024). Effects of traffic-related air and noise pollution exposure on allergic diseases in the elderly: An observational study. *Annals of Medicine, 56*(1), 2398193. https://doi.org/10.1080/07853890.2024.2398193
12. Park, K. H., Sim, D. W., Lee, S. C., Moon, S., Choe, E., Shin, H., Kim, S. R., Lee, J. H., Park, H. H., Huh, D., & Park, J. W. (2020). Effects of air purifiers on patients with allergic rhinitis: A multicenter, randomized, double-blind, and placebo-controlled study. *Yonsei Medical Journal, 61*(8), 689–697. https://doi.org/10.3349/ymj.2020.61.8.689
13. Cavalier, A., Dick, A. I., Johnson, V., II, Cramer, E., Eldeirawi, K., Pinto, J., Nyenhuis, S. M., & Lee, V. S. (2025). Assessing the impact of home environmental exposures on allergic rhinitis using real-time air quality monitoring and symptom assessment: Observational feasibility study. *JMIR Formative Research, 9*, e73215. https://doi.org/10.2196/73215
14. Massey, C. J., Tullis, B., Johnson, C., Oakley, G., Orlandi, R., Alt, J., Pulsipher, A., Gill, A., Horel, J., & Smith, K. (2025). Characterizing air pollution exposure methodologies in rhinology: A scoping review. *International Journal of Environmental Health Research, 35*(11), 3588–3603. https://doi.org/10.1080/09603123.2025.2477585
15. Gharbi, D., Neumann, F. H., Staats, J., McDonald, M., Linde, J. H., Mmatladi, T., Podile, K., Piketh, S., Burger, R., Garland, R. M., Bester, P., Lebre, P. H., & Ricci, C. (2025). Prevalence of aeroallergen sensitization in a polluted and industrialized area: A pilot study in South Africa's Vaal Triangle. *Environmental Monitoring and Assessment, 197*(3), 287. https://doi.org/10.1007/s10661-025-13718-y
16. Li, J., Feng, C., Ma, X., & Wu, D. (2025). Impact of the urban atmospheric environment on otolaryngologic disease outpatient visits in Lanzhou, China. *Scientific Reports, 15*(1), 21556. https://doi.org/10.1038/s41598-025-07352-4
17. Abramson, M. J., Wigmann, C., Altug, H., & Schikowski, T. (2020). Ambient air pollution is associated with airway inflammation in older women: A nested cross-sectional analysis. *BMJ Open Respiratory Research, 7*(1), e000549. https://doi.org/10.1136/bmjresp-2019-000549
18. Zhang, Z.-Q., Li, J.-Y., Guo, Q., et al. (2025). Association between air pollution and allergic upper respiratory diseases: A meta-analysis. *European Respiratory Review, 34*, 240266. https://doi.org/10.1183/16000617.0266-2024
19. Nagino, K., Inomata, T., Ebihara, N., Midorikawa-Inomata, A., Fujio, K., Kobayashi, H., & Nakao, S. (2026). Association between yellow dust, PM2.5, and hay fever: A large-scale crowdsourced observational study using the AllerSearch smartphone application. *Allergology International, 75*(2), 294–306. https://doi.org/10.1016/j.alit.2025.11.008

20. Kim, J. Y., Lee, D. S., Woo, H. J., Kim, H. G., Son, B. S., Park, M. K., & Hong, S. N. (2021). Impact of particulate matter on the clinical characteristics of rhinitis. *The Laryngoscope, 131*(6), E1753–E1759. https://doi.org/10.1002/lary.29185
21. Rosario, C. S., Urrutia-Pereira, M., Murrieta-Aguttes, M., D'Amato, G., Chong-Silva, D. C., Godoi, R. H. M., & Rosario Filho, N. A. (2024). Air pollution and rhinitis. *Frontiers in Allergy, 5*, 1387525. https://doi.org/10.3389/falgy.2024.1387525
22. Li, J., Wu, H., Xing, W., Li, X., Han, Z., Ji, R., Deng, Z., Jung, M., Sun, S., Chung, B. I., Cardenas, A., & Langston, M. E. (2024). Air pollution mixture associated with oxidative stress exacerbation and symptoms deterioration in allergic rhinitis patients: Evidence from a panel study. *Science of the Total Environment, 930*, 172688. https://doi.org/10.1016/j.scitotenv.2024.172688
23. Pisithkul, T., Pisithkul, T., & Lao-Araya, M. (2024). Impact of air pollution and allergic status on health-related quality of life among university students in Northern Thailand. *International Journal of Environmental Research and Public Health, 21*(4), 452. https://doi.org/10.3390/ijerph21040452
24. European Forum for Research and Education in Allergy and Airways Diseases. (2020). *Allergic rhinitis in adults*. https://www.euforea.org/news/allergic-rhinitis-pocket-guide/
25. World Health Organization. (2021). *WHO global air quality guidelines: Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. https://www.who.int/publications/i/item/9789240034228
26. World Health Organization. (2025). *Health risks of air pollution in Europe: HRAPIE-2 project: Updated guidance on concentration–response functions for health risk assessment of air pollution in the WHO European Region*. https://www.who.int/publications/i/item/9789289062633
27. Wang, G. F., Zhang, Y. Z., Yang, H. Y., Yang, Y., Dong, L., Zhang, P., Liu, J., Chen, X. D., & Gong, Y. (2024). Impact of air pollutants on lung function and inflammatory response in asthma in Shanghai. *Biomedical and Environmental Sciences, 37*(8), 811–822. https://doi.org/10.3967/bes2024.125