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Climate change and allergic diseases: A comprehensive review of current evidence and future implications

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Abstract

Climate change is increasingly recognized as a significant threat to public health, with mounting evidence suggesting its profound impact on allergic diseases. This comprehensive review discusses the intricate relationship between climate change and allergic conditions, focusing on allergic rhinitis, asthma, and atopic dermatitis. We synthesize current research on how climate-induced alterations in temperature, precipitation patterns, and atmospheric composition affect the production, distribution, and allergenicity of aeroallergens. Furthermore, we explore the mechanisms by which these changes influence the prevalence, severity, and phenotypes of allergic diseases. The review also discusses the broader public health implications, including the economic burden and impact on quality of life. Finally, we present potential mitigation strategies and areas for future research, emphasizing the need for interdisciplinary approaches to address this growing global health concern.

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Highlights

What is current knowledge?

- Climate change influences allergic diseases such as rhinitis, asthma, and dermatitis by altering aeroallergen exposure.
- Rising CO_2 levels and temperatures extend pollen seasons, increase pollen production, and shift plant distribution.
- Global studies show a rising prevalence and severity of allergic diseases linked to environmental changes.

What is new here?

- Provides a comprehensive 2000-2024 synthesis linking climate-induced aeroallergen changes with allergic disease outcomes.
- Explores novel mechanisms-epithelial barrier dysfunction, immune modulation, and microbiome alterations.

Introduction

The earth's climate is changing at an unprecedented rate, with far-reaching consequences for human health and well-being. Among the myriad health impacts of climate change, its effect on allergic diseases has emerged as a significant concern (1). Allergic diseases, including allergic rhinitis, asthma, and atopic dermatitis, affect a substantial portion of the global population and have shown a marked increase in prevalence over recent decades (2). The rising incidence of allergic diseases represents a global health challenge of growing importance. Over the past half-century, there has been a notable surge in the prevalence of allergic conditions, particularly in industrialized nations, a phenomenon often referred to as the "allergy epidemic" (3). According to the World Allergy Organization, the prevalence of allergic diseases has been rising by 3-4% per year globally (4). This trend is particularly pronounced in children, with some regions reporting that up to 40% of children are now affected by allergic rhinitis (5).

The increase in allergic diseases is evident across various conditions: Allergic Rhinitis: Often referred to as hay fever, allergic rhinitis has seen a significant increase in prevalence. The International Study of Asthma and Allergies in Childhood (ISAAC) reported that the global prevalence of allergic rhinoconjunctivitis symptoms in children increased from 12.9% to 14.6% over a 7-year period (5). Asthma: The global burden of asthma has risen substantially. The Global Asthma Report 2018 estimates that asthma affects around 339 million people worldwide, a number that has increased by 30% since 2008 (6). Food Allergies: The prevalence of food allergies, particularly in children, has increased dramatically. In the United States, for example, the prevalence of peanut or tree nut allergy among children more than tripled between 1997 and 2008 (7). Atopic Dermatitis: Also known as eczema, atopic dermatitis has shown an upward trend in many countries. The prevalence in children has reached 15-30% in industrialized countries and up to 10% among adults (8).

This rising trend in allergic diseases is attributed to a complex interplay of genetic and environmental factors. While genetic predisposition plays a role, the rapid increase in prevalence over a relatively short time span suggests that environmental and lifestyle factors are significant contributors (9). Among these environmental factors, climate change has emerged as a crucial potential driver of the observed increases in allergic diseases. The intricate relationship between climate change and allergic diseases is multifaceted, involving complex interactions between environmental factors, allergens, and human physiology. As global temperatures rise and weather patterns shift, we observe changes in the distribution, abundance, and allergenicity of various aeroallergens, particularly pollen and mold spores (10). These changes, in turn, have profound implications for the millions of individuals who suffer from allergic conditions worldwide.

Climate change affects allergic diseases through several mechanisms as follows: Extended pollen seasons and increased pollen production, leading to greater allergen exposure (11). Changes in the geographical distribution of allergenic plants, introducing new allergens to different regions (12). Increased production of allergenic proteins in plants due to environmental stress (13). Interactions between air pollutants and allergens, potentially enhancing their allergenic properties (14). Alterations in indoor environments that may promote the growth of indoor allergens such as mold and dust mites (15). Understanding these complex interactions is crucial for addressing the growing burden of allergic diseases in the context of ongoing climate change. This review aims to present a comprehensive overview of the current state of knowledge regarding the impact of climate change on allergic diseases. We will examine the evidence linking climate-induced environmental changes to alterations in allergen exposure and the subsequent effects on allergic disease patterns. Furthermore, we will explore the potential mechanisms underlying these relationships, discuss the broader public health implications, and consider strategies for mitigation and adaptation.

By synthesizing the latest research in this field, we hope to contribute to a better understanding of how climate change influences allergic diseases and to inform strategies for managing this significant public health challenge in a changing climate. While several reviews have examined the relationship between climate change and allergic diseases, this article offers a comprehensive, up-to-date synthesis focusing specifically on aeroallergens and their clinical impact, with emphasis on recent epidemiological trends and mechanistic insights. Unlike earlier reviews, this paper integrates global patterns with emerging mitigation strategies and highlights evidence from low- and middle-income countries, an area often underrepresented in previous literature.

Methods

This review was conducted to systematically examine the relationship between climate change and allergic diseases, with a specific focus on aeroallergens such as pollen and fungal spores. A comprehensive literature search was conducted across multiple scientific databases, including PubMed, Google Scholar, ScienceDirect, and Scopus.

The search strategy employed combinations of keywords and phrases such as: *"climate change,"* "allergic diseases," "asthma," "rhinitis," "atopic dermatitis," "aeroallergens," "pollen," "fungal spores," and "global warming." The search was restricted to peer-reviewed articles published between 2000 and 2024.

Study selection

A total of 30 studies were included in this review. These studies were selected based on their relevance to the review objective and their fulfillment of the following criteria:

Inclusion criteria

Peer-reviewed studies focusing on the impact of climate change on allergic diseases. Human and environmental studies that link climate variables (e.g., temperature, CO_2 levels, precipitation) to allergen production, distribution, exposure, or disease outcomes.

Exclusion criteria

Articles not published in peer-reviewed journals. Studies unrelated to allergic diseases or that focused exclusively on non-atopic conditions. Literature discussing food allergies or non-aeroallergen pathways without relevance to climate variables.

Scope of review

This review focuses specifically on aeroallergens (Such as pollen and mold spores) and their influence on respiratory and dermatologic allergic diseases (e.g., allergic rhinitis, asthma, and atopic dermatitis). Food allergies and non-atopic immune disorders were deliberately excluded to maintain a clear and manageable scope. The methods and criteria described above were followed to ensure transparency, scientific rigor, and relevance to the current climate-health discourse.

Climate change and allergen dynamics

Effects on pollen production and distribution

Climate change significantly influences the production and distribution of allergenic pollen through various mechanisms. Rising temperatures and elevated atmospheric CO_2 levels have been shown to affect plant phenology, potentially leading to earlier and longer pollen seasons. For instance, studies have demonstrated that the ragweed (Ambrosia artemisiifolia) pollen season has extended by up to 27 days at latitudes above 44°N in North America since 1995 (11). Moreover, increased atmospheric CO_2 concentrations can stimulate plant growth and pollen production. Experimental studies have shown that ragweed plants grown under elevated CO_2 conditions produce significantly more pollen than those grown under ambient conditions (16). This increase in pollen production, coupled with extended pollen seasons, results in higher overall airborne pollen concentrations, potentially increasing allergen exposure for susceptible individuals.

A key study by Ziska et al. (10) conducted a retrospective analysis of airborne pollen data across 17 sites in North America and Asia from 1990 to 2018 to investigate the impact of rising temperatures on pollen abundance and seasonality. The study revealed that 71% of the monitored sites experienced a significant increase in annual pollen concentrations, while 65% showed extended pollen seasons, averaging an increase of 0.9 days per year. These changes were significantly associated with rising mean temperatures, particularly increases in daily minimum temperatures and the number of frost-free days.

The monitored sites included cities across the United States such as Ann Arbor (MI), Appleton (WI), Baltimore (MD), Baton Rouge (LA), Denver (CO), Fargo (ND), Kansas City (MO), Lincoln (NE), Madison (WI), Minneapolis (MN), New Orleans (LA), Reno (NV), San Jose (CA), Tampa (FL), and Tucson (AZ), as well as Winnipeg (Canada) and Yokohama (Japan). This broad geographic coverage allowed the study to capture a range of climatic zones and provided compelling evidence that climate warming is driving both increased pollen loads and longer pollen seasons across the Northern Hemisphere.

These findings underscore the potential for intensified allergen exposure, especially in temperate regions, and highlight the importance of integrating climate projections into aeroallergen surveillance and public health planning. Climate change profoundly influences the geographical distribution of allergenic plant species. Rising global temperatures, earlier springs, and extended growing seasons are enabling thermophilic plants-such as ragweed (Ambrosia artemisiifolia) and various grass species-to expand their habitats northward and to higher altitudes. For instance, evidence from Europe and North America indicates that ragweed has expanded its range by over 400 km northward in some areas over the past three decades (11). Similarly, allergenic birch pollen has been observed at increasing concentrations in parts of Scandinavia where it was historically minimal (12).

This latitudinal and altitudinal shift is particularly concerning for regions previously considered low-risk for pollen-related allergic diseases. As a result, populations in these areas may experience new exposures to allergens, increasing the likelihood of de novo sensitization and contributing to the emergence of novel allergy hotspots. Moreover, individuals with pre-existing allergies may experience more prolonged and severe symptoms due to both increased exposure duration and co-existence of multiple pollen types in the same regions. These ecological changes, driven by climate-induced shifts in vegetation zones, demand close monitoring and integration into public health allergy forecasting systems to anticipate and mitigate rising disease burden in vulnerable populations.

Impact on fungal spores and indoor allergens

While much attention has been focused on pollen, climate change also affects the production and distribution of fungal spores and indoor allergens. Increased temperatures and humidity levels associated with climate change can promote mold growth, potentially leading to higher concentrations of airborne fungal spores (15). Climate-related changes in precipitation patterns, including more frequent extreme weather events such as floods and hurricanes, can create ideal conditions for mold growth in indoor environments. Such an increase in indoor mold exposure may contribute to a rise in allergic respiratory symptoms and asthma exacerbations (1). Furthermore, climate change may indirectly influence indoor allergen levels through changes in human behavior. For example, increased use of air conditioning in response to higher temperatures can create favorable conditions for dust mites, potentially increasing exposure to this common indoor allergen (17).

Climate change and allergic diseases

Allergic rhinitis

Allergic rhinitis, commonly known as hay fever, is one of the most prevalent allergic conditions affected by climate change. The extended pollen seasons and increased pollen concentrations associated with climate change have significant implications for individuals with allergic rhinitis. Studies have shown that changes in pollen seasons correlate with changes in the timing and duration of allergic rhinitis symptoms (18). Longer pollen seasons may lead to prolonged periods of symptoms for affected individuals, potentially increasing the burden of the disease and impacting quality of life. Moreover, higher pollen concentrations can result in more severe allergic reactions and potentially increase the risk of new sensitizations. A study by Damialis et al. (19) found a correlation between higher pollen concentrations and increased rates of allergic sensitization, suggesting that climate-induced changes in pollen levels may contribute to a rise in allergic rhinitis prevalence.

Asthma

Climate change exacerbates asthma symptoms and may contribute to increased asthma prevalence through various mechanisms. Higher pollen counts and extended pollen seasons can trigger asthma attacks in sensitized individuals, leading to more frequent exacerbations and potentially more severe symptoms (1). In addition to its effects on aeroallergens, climate change is associated with increased air pollution, particularly ground-level ozone and particulate matter. These pollutants can interact synergistically with allergens, potentially enhancing their allergenic properties and exacerbating asthma symptoms (14). Extreme weather events, which are becoming more frequent due to climate change, have also been linked to asthma exacerbations. For example, thunderstorms can cause a phenomenon known as "thunderstorm asthma," in which pollen grains rupture due to osmotic shock, releasing respirable allergenic particles that can trigger severe asthma attacks (17,20).

Atopic dermatitis

While the relationship between climate change and atopic dermatitis (Eczema) is less direct than for respiratory allergies, emerging evidence suggests potential impacts. Changes in temperature and humidity associated with climate change may affect skin barrier function and potentially exacerbating symptoms in individuals with atopic dermatitis (21). Climate-induced changes in allergen distribution may also influence eczema triggers. For instance, the spread of new plant species into different regions could introduce novel contact allergens, potentially increasing the risk of contact dermatitis in susceptible individuals (22). Moreover, increased frequency of extreme weather events and natural disasters associated with climate change may lead to forced migration and changes in living conditions, potentially exposing individuals to new environmental triggers for atopic dermatitis (15) (Table 1).

Table 1. Summary of climate change impacts on aeroallergen dynamics and related allergic diseases

Climate variable	Impact on allergens	Affected allergic condition
Increased CO_2 levels	Increased pollen production	Allergic rhinitis, Asthma
Rising temperature	Extended pollen seasons	Asthma, Rhinitis
Increased humidity	Promoted mold growth	Asthma, Dermatitis
Extreme weather events	Thunderstorm asthma	Asthma

Mechanisms linking climate change to allergic diseases

Several mechanisms have been proposed to explain the relationship between climate change and the observed increases in allergic diseases: Increased allergenicity of pollen: Higher temperatures and CO_2 levels may not only increase pollen production but also enhance the allergenic potential of pollen grains. Studies have shown that pollen produced under elevated CO_2 conditions contains higher concentrations of allergenic proteins (13). Altered immune responses: Environmental stressors associated with climate change, such as heat stress and air pollution, may modulate immune system function, potentially increasing susceptibility to allergic sensitization and exacerbating allergic responses (23). Epithelial barrier dysfunction: Changes in temperature, humidity, and air pollution levels can affect the integrity of respiratory and skin epithelial barriers, potentially facilitating allergen penetration and sensitization (24). Altered microbial exposure: Climate change may influence the diversity and composition of environmental microbiomes, which play a crucial role in immune system development and function. Changes in microbial exposure patterns may contribute to altered risk of allergic sensitization (25). Synergistic effects with air pollution: Climate change and air pollution are closely interlinked, with many air pollutants also acting as greenhouse gases. The interaction between allergens and air pollutants can enhance the allergenic potential of pollen and may increase the risk of allergic sensitization and exacerbation of symptoms (14).

Public health implications

The impact of climate change on allergic diseases has significant public health implications as follows: Increased healthcare costs: The rising prevalence and severity of allergic diseases associated with climate change are likely to result in increased healthcare utilization and costs. A study by Zuberbier et al. (25) estimated that the total cost of allergic diseases in the European Union exceeds €150 billion annually, a figure that may rise with climate change. Reduced quality of life: Allergic diseases significantly impact quality of life, affecting sleep, work productivity, and daily activities. Climate-induced changes in allergen exposure may lead to more prolonged and severe symptoms, further diminishing quality of life for affected individuals (26). Occupational impacts: Changes in pollen seasons and distribution may affect outdoor workers, particularly in agriculture and forestry. This could lead to increased occupational allergies and asthma, potentially impacting workforce productivity (15). Environmental justice concerns: The health impacts of climate change, including those related to allergic diseases, are likely to disproportionately affect vulnerable populations, including children, the elderly, and low-income communities, raising important environmental justice concerns (27). Global health security: Climate-induced changes in allergen distribution and disease patterns may contribute to broader global health security challenges, including potential impacts on food security and population displacement (28).

Mitigation strategies and future directions

Addressing the impact of climate change on allergic diseases requires a multifaceted approach involving both mitigation of climate change itself and adaptation strategies to reduce its health impacts. Some potential strategies include Improved pollen forecasting: Developing more accurate and localized pollen forecasting systems can help individuals with allergies better manage their exposure and symptoms (29). Urban planning and green spaces: Implementing climate-resilient urban planning strategies, including the careful selection of plant species for urban green spaces, can help reduce allergen exposure in urban environments (30). Building design: Incorporating climate change considerations into building design, including improved ventilation and filtration systems, can help reduce indoor allergen exposure (31). Public education: Enhancing public awareness about the links between climate change and allergic diseases can promote individual and community-level adaptation strategies (24). Health system preparedness: Strengthening health systems to better respond to climate-related changes in allergic disease patterns, including improved surveillance and early warning systems (28). Interdisciplinary research: Promoting interdisciplinary research collaborations between climatologists, aerobiologists, immunologists, and public health experts to better understand and address the complex interactions between climate change and allergic diseases (22).

Conclusion

This review confirms that climate change is a significant and growing driver of allergic diseases, particularly through its effects on aeroallergen dynamics and environmental conditions that influence sensitization and disease exacerbation. The impact of climate change on allergic diseases represents a significant and growing public health concern. The evidence reviewed here demonstrates that climate-induced changes in temperature, precipitation patterns, and atmospheric composition are altering the production, distribution, and allergenicity of aeroallergens, with consequent effects on the prevalence and severity of allergic diseases. As we face the challenges posed by climate change, it is crucial to adopt a proactive and interdisciplinary approach to mitigate its impacts on allergic diseases. This will require continued research to better understand the underlying mechanisms, improved surveillance and forecasting systems, and the development of innovative adaptation strategies. Moreover, addressing this issue necessitates broader action on climate change mitigation. Reducing greenhouse gas emissions and limiting global temperature rise is essential not only for preserving environmental stability but also for protecting public health from the myriad impacts of climate change, including its effects on allergic diseases. As we move forward, it is clear that the intersection of climate change and allergic diseases will remain a critical area of focus for researchers, healthcare providers, policymakers, and the public alike. By working together across disciplines and sectors, we can develop effective strategies to safeguard public health in the face of our changing climate. While the evidence linking extended pollen seasons to increased allergic rhinitis is strong and supported by multiple longitudinal studies (10,18), other pathways such as the impact of climate-altered microbiota on immune function require further exploration through longitudinal cohort studies and controlled experiments. Further, future research should focus on long-term, multi-center allergen surveillance systems that are integrated with real-time climate data to better understand and predict trends in allergen exposure. Additionally, mechanistic studies exploring the interactions between air pollutants and pollen at the molecular and immunological levels are essential to clarify their combined effects on allergic disease onset and severity. Clinical cohort studies assessing allergen-specific sensitization trends across various geographic and climatic zones would further elucidate population-level vulnerabilities. Finally, the development and application of AI-driven pollen prediction models could significantly enhance public health advisories and preparedness, particularly in high-risk regions.

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Conflicts of interest

The authors declare no conflict of interest.

Author contributions

PK searched literature, conceived the study, and wrote the manuscript, reviewed and edited the manuscript and approved the final version of the manuscript.

Data availability statement

This review is based on existing studies and publicly accessible data. No new datasets were created or analyzed in this research.

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