HALEON

Table of Contents

Climate change impact on Respiratory Health

Key Takeaways

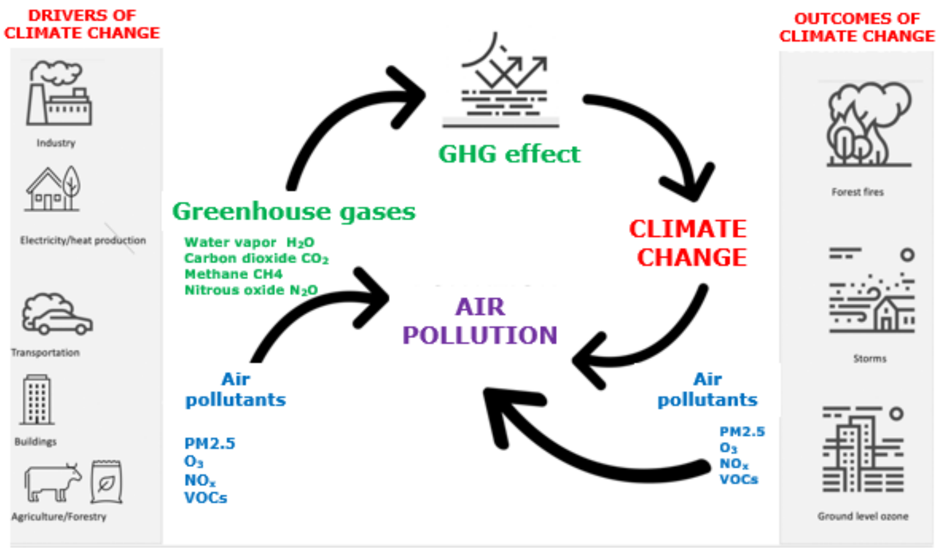
- Human reliance on fossil fuels has increased greenhouse gases and air pollutants, causing an 18°C global temperature rise.
- Climate change effects include extreme temperatures, rising sea levels, altered precipitation, and intensified extreme weather events, it impacts local weather and air pollutant distribution, worsening air quality.
- Climate change significantly influences the onset and progression of pollen allergies. It boosts pollen production and alters their allergenic properties.
- Temperature changes can trigger inflammation, oxidative stress, and immune system alterations.
- Climate change affects prevalent respiratory conditions such as asthma, allergic rhinitis, and chronic rhinosinusitis/sinusitis, cold and influenza.
- Mortality and hospitalization rates are influenced by temperature variability and extreme weather events.
- Elderly individuals, pregnant women, children, urban residents, and those with lower socioeconomic status are particularly vulnerable to the health impacts of climate change.
- Social inequalities contribute to the disproportionate effects of climate change on vulnerable populations, necessitating tailored interventions.
- There is a strong correlation between heating homes in winter and the rise in respiratory conditions. On one hand, evidences favor warmer room temperatures for reduced asthmatic symptoms, while also discuss the increased particulate matter pollution with the use of heating through coals.

A. Drivers of Climate Change

Human reliance on fossil fuels has resulted in higher concentrations of greenhouse gases (GHGs) responsible for climate change and other air pollutants. Since the Industrial Revolution, the atmospheric CO_2 concentration has surged from 280 ppm to over 415 ppm, leading to an 18°C (28°F) rise in global average surface temperature compared to preindustrial levels. Recent decades have seen a rapid increase in global warming, with 7 of the 10 warmest years occurring since 2014. If the current trends continue, the warming is projected to reach 1.5-2°C between 2030 and 2052.

The consequences of climate change include higher temperatures, heat waves, rising sea levels, altered precipitation patterns, changes in plant growth seasons, increased intensity of extreme weather events, droughts, and shifts in the distribution of infectious disease vectors.

Climate change also impacts local weather and meteorological variables, influencing the distribution of air pollutants. Climate-induced phenomena such as wildfires, storms, increased pollen levels, and heatwaves necessitating higher energy consumption further exacerbate both biological and human-made sources of air pollution, creating a self-reinforcing cycle of poor air quality and pollution resulting from climate change. (Pacheco et al 2022)



1. Temperature changes and heat waves

Rising temperatures due to climate change have increased the frequency and intensity of extreme heat, leading to a significant 37.0% mortality burden during warm seasons from 1991-2018. Non-optimum temperatures can worsen asthma symptoms, while both extreme cold and heat are linked to decreased pulmonary function in adult asthmatic patients.

In a study by Lei J et al 2022, compared with referent temperature (29.5 ◦C), extreme high temperature (34.2 ◦C) was associated with decreases of 26.0 mL in FEV1, 35.8 mL/s in PEF, and 23.4 mL in FVC. Vulnerable populations include males, the elderly, and those who are overweight, with cold effects more pronounced in southern regions without central heating. (Lei J et al., 2022)

2. Increased pollen seasons and allergen exposure

Climate change significantly influences the onset and progression of pollen allergies. It boosts pollen production and alters their allergenic properties. Climate-induced changes in plant growth lead to the production of modified pollen, adversely affecting human health. (Gennaro D Amato et al 2023)

Air pollutants and allergens interact, heightening the risk of allergic sensitization and symptom exacerbation. Pollen allergenicity is amplified by air pollution. Both biological (pollen) and non-biological particulates (carbon, silica, metals, ultrafine dust) interact in the atmosphere, impacting public health directly through irritation or interactions among different particulate types.

3. Extreme weather events

Extreme weather events, increasingly common due to climate change, have been linked to a rise in asthma-related incidents. Heatwaves, cold spells, dust storms, hurricanes, floods, and storm surges worsen existing respiratory conditions and elevate the likelihood of asthma-related problems.

Notably, hurricanes are a significant risk for asthma events in the United States, while thunderstorms pose similar risks in North American and European regions. In Australia, two studies highlight, thunderstorm asthma has led to 10 deaths and approximately 9000 hospital and emergency department visits for severe and near-fatal asthma.

Children are particularly vulnerable to asthma during extreme weather occurrences. Studies in the United States have shown that floods increase the risk of asthma symptoms by 1.86- and 1.04-fold. Females, especially, experience more severe wheezing incidents during extreme weather events. Furthermore, an increase in floods raises the relative risk of asthma diagnosis by 2.16-fold, while previous studies have highlighted the impact of extreme weather events, such as ice storms, on the incidence of asthma.

In summary, **the increasing frequency of extreme weather events is associated with a higher risk of various asthma outcomes**, particularly in vulnerable populations like children and females. (Makrufardi F et al 2023)

Weather Event	Relative risk of Asthma (95% CI)
Blizzard/ice storms	1.10 (1.03-1.17)
Cold spells	1.08 (0.98-1.19)
Dust storm	1.11 (1.04-1.18)
Flood	1.43 (1.11-1.84)
Heat wave	1.19 (1.04-1.38)
Hurricane/Typhoon	1.50 (0.93-2.43)
Thunderstorm	1.24 (1.13-1.36)

4. Thunderstorms and asthma

Climate change is also associated with the increase in frequency and intensity of thunderstorms, which can result in thunderstorm asthma, an observed increase in acute bronchospasm cases following thunderstorms in the local vicinity. Thunderstorms occurring during the pollen season have induced severe asthma attacks and deaths in patients with pollen allergy. Events from Europe, North America, the Middle East, and Australia have been reported.

Thunderstorm asthma events have led to a ten-fold increase in asthma admissions and significant impacts on healthcare resources, with individuals having a history of allergic rhinitis facing a higher risk - over 90 % of affected cases show sensitization to triggering allergens, making geographical areas with specific risk factors more susceptible to thunderstorm asthma epidemics (Kevat, 2020). Future predictions indicate that episodes may become more frequent due to climate changes, making implementing preventive strategies and public health messages vital to mitigate the impact of thunderstorm asthma. (D'Ammato G et al 2012)

5. Wildfires

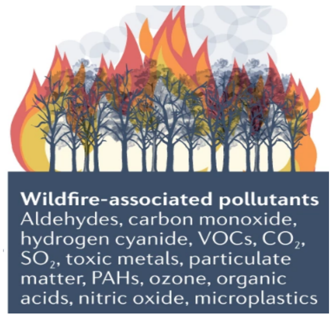
Climate-induced droughts lead to more severe and frequent wildland fires, causing both airway and systemic inflammation. Studies on wildland firefighters and exposure to wood smoke particles reveal compromised lung function and airway inflammation.

Wildfire smoke exposure alters key immune pathways, such as aryl hydrocarbon receptor, Toll-like receptor, and NF-κB signaling, leading to upregulated pro-inflammatory cytokines and reactive oxygen species. Firefighters exposed to wildfires exhibit increased pulmonary and systemic inflammation, with elevated IL-6 and IL-12 levels and decreased IL-10 levels.

Additionally, a recent study highlights how PM2.5 pollution from wildfires worsens mortality and morbidity from infectious diseases, including COVID-19. The research suggests that wildfire smoke exacerbates the negative effects of PM2.5 on COVID-19 cases and deaths for up to four weeks. This underscores the perilous combination of wildfires and airborne diseases, potentially disrupting immune and lung epithelial barrier function.
(Akdis CA et al 2022)

Immune system

- Reduced function
- ↑ Infection RISK
- ↑ Inflammation
- ↑ Oxidative stress
- ↑ Activation of TLRs and inflammasome
- Epigenetic changes



Airways

- ↑ **Inflammation**
- TLR activation
- Epithelial barrier damage
- Lung damage
- ↑ Autophagy
- ↑ Cell death
- ↑ Fibrosis

6. Air pollution

At least 90% of the world's population live in areas with low air quality, where the concentration of pollutants exceeds the guidelines established by the World Health Organization (WHO). In the United States, more than 40% of the population (more than 135 million individuals) live in areas with poor air quality. In 2015, PM2.5 was responsible for 4.2 million premature deaths per year worldwide, with more than 92% of pollution-related deaths occurring in low-income and middle-income countries.

Climate change and air pollution are intimately intertwined, amplifying each other's effect. Global warming is primarily caused by greenhouse gas emissions such as carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), mainly from fossil fuel combustion, deforestation, and agriculture (IPCC, 2021). Inversions occur when warm air settles above cooler air, trapping pollutants and hindering their dispersion in the atmosphere, leading to increased levels of air pollution during high-pressure periods (Ramanathan, 2020). When extreme weather events such as heatwaves, storms, and wildfires occur, air pollution can become a severe problem. (Tran HM et al. 2023)

Air pollution has also been linked with increased susceptibility to respiratory viral infections through various mechanisms, including increased epithelial cell permeability, changes in expression of epithelial cell–bound viral receptors, and impaired antiviral immunity. Exposure to atmospheric pollutants has been associated with respiratory viral infections, such as influenza, measles, mumps, rhinovirus, and respiratory syncytial virus. Epidemiologic studies have also suggested that exposure to air pollution is associated with the increase in infection by SARS-CoV-2 and mortality associated with COVID-19. Exposure to atmospheric pollutants can predispose vulnerable and immunocompromised populations to development of a more intense inflammatory response and tissue damage by COVID-19.

Of the people that do not live in areas that have acceptable air quality, 98% come from poorer countries, while only 56% come from high-income nations. This is also probably why more than 90% of air pollution-related deaths occur in low and middle-income countries. The reason for this is due to a combination of weak environmental laws and reliance on cheap, outdated technologies (like coal power stations) in such regions.

B. Biological pathways to respiratory health under climate change

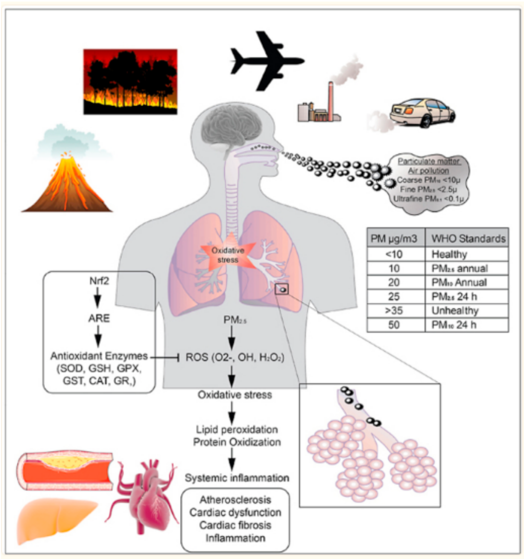
Changes in climate variables, particularly temperature, can affect respiratory health through various physiological mechanisms, including inflammation, oxidative stress, and immune system modulation (Grigorieva and Lukyanets, 2021). Increased temperature disrupts cellular balance, generating reactive oxygen species (ROS) and causing oxidative damage to cells and tissues (Jacobs et al., 2020). This imbalance triggers inflammation and lung tissue damage, leading to respiratory symptoms and disorders (Deng et al., 2020).

Mechanistic studies have shown that PM results in increased epithelial permeability, airway hyperresponsiveness, oxidative stress, immune dysregulation, and epigenetic changes.

The oxidative stress response triggered by air pollution can promote epigenetic modifications that regulate gene expression of immune cells, including modification of regulatory T cells and the important immunoregulatory genes Forkhead box P3 (FOXP3), IL4, IL10, and interferon gamma (INFG) through DNA methylation. Clinically, increased methylation of FOXP3 secondary to air pollution exposure has been associated with increased risk of asthma.

Furthermore, temperature shifts can prompt the release of proinflammatory cytokines, potentially worsening existing respiratory conditions (Grigorieva and Lukyanets, 2021). Climate change's impact extends to the immune system, potentially altering responses to respiratory infections, affecting infection severity and duration, and influencing the growth and survival of respiratory pathogens, ultimately changing the prevalence and transmission of respiratory infections.

Climate change also impacts allergen distribution, like pollen, causing changes in the prevalence of respiratory allergies (D'Amato et al., 2020). The effect of relative humidity (RH) on respiratory diseases is complex and warrants further comprehensive study to better understand this relationship (Guarnieri et al., 2023). Additionally, certain extreme weather events attributed to climate change can adversely affect respiratory health (Di Cicco et al., 2020). (Fig: Gangwar RS et al 2020)



C. Impact of climatic changes

The health impacts of climate change are pervasive and multisystemic, affecting most, if not all, organ systems. Chronic medical disorders, including the following, will continue to increase because of climate change: cardiovascular, cerebrovascular, renal, and respiratory diseases; neurodegenerative conditions and mental disease; atopic and infectious diseases; metabolic disorders; and malignancy.

1. Asthma

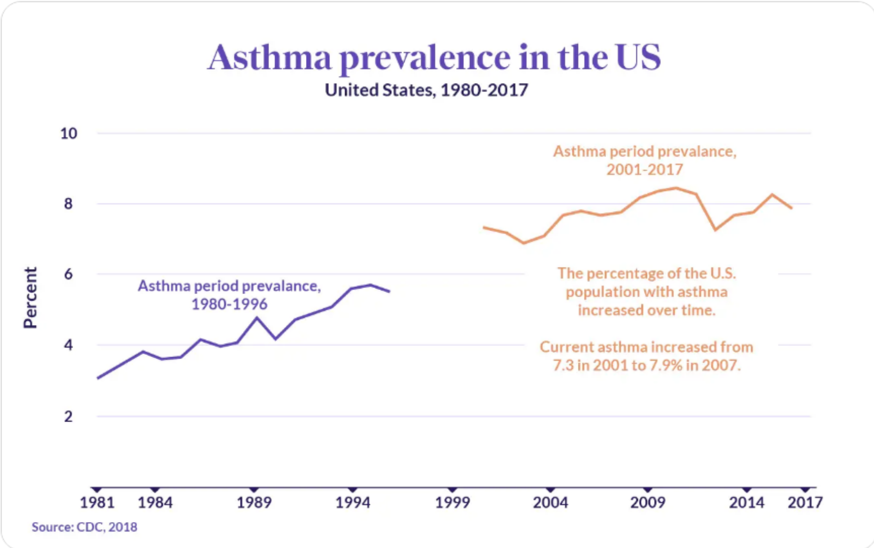
Between 1990 and 2019, the global median incidence of asthma was 402.0 per 100,000 with a higher incidence (median: 1380.3 per 100,000) in children under 10 years old. A study by Qingsong Xu reported that every 1 °C increase in maximum temperature variability increased the risk of asthma globally by 5.0%, and the effect was robust for individuals living in high-latitude areas or aged from 50 to 70 years. (Qingsong Xu et al 2023; PMID: 37659541)

The largest study in China (n=184,047) to comprehensively quantify the association between temperature variability (TV) and common diseases among the elderly concluded that in general, there were significant associations between TV and the prevalence of most diseases at the national level. Cardio-cerebrovascular disease (OR: 1.16, 95% CI: 1.13, 1.20) generated the highest estimates, followed by stomach diseases (OR: 1.15, 95% CI: 1.10, 1.19), asthma (OR: 1.14, 95% CI: 1.06, 1.22), chronic lung diseases (OR: 1.08, 95% CI: 1.03, 1.13). (Temperature variability and common diseases of the elderly in China: a national cross-sectional study | Environmental Health | Full Text (biomedcentral.com))

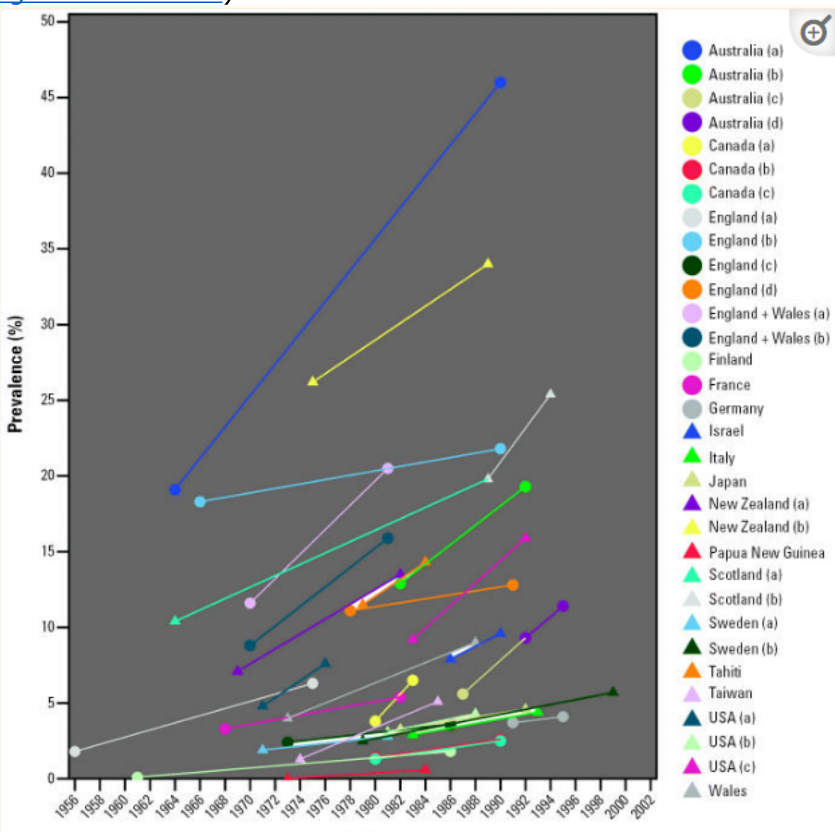
Asthma alone accounts for around 400,000 fatalities worldwide each year (WHO, 2020). Climate change, in combination with air pollution, may contribute to asthma development (Eguiluz-Gracia et al., 2020). A correlation in one study showed that an increase of 10 μg/m3 in PM2.5 and PM10 concentrations was associated with a 14 % (odd ratio (OR) = 1.14; 95 % confidence interval (CI) 1.03–1.26) and 11 % (OR = 1.11; 95 % CI 1.02–1.20) increase in the odds of childhood asthma respectively (Wu et al., 2022). Another review found increased asthma incidence among young people when ambient PM2.5 levels increased by 1 μg/m3. (Tran HM et al. 2023)

Over the past 40 years, the number and severity of asthma cases have been steadily increasing with no anticipation of slowing down. The latest numbers in 2019 show that asthma affected approximately 262 million people globally and was the cause of 461,000 deaths.

In the US, the rate of prevalence of asthma was only 3.1% in 1980. This increased to 7.8% in 2019, and asthma emergency department visit rates have also risen by about 10% from 2006 to 2014. Researchers are saying that climate change may be to blame as it changes the quality of the air we breathe.



Global Asthma prevalence: Evidence for the global increase in the burden of asthma has come from studies of incidence, prevalence, and morbidity. Asthma prevalence appears to have increased since the early 1960s ([Begs PJ et al 2005](#))



2. Allergic rhinitis

Allergic rhinitis is a globally prevalent allergic disease, with a significant link to air pollution exposure. A comprehensive meta-analysis, which included 35 studies across 12 countries with a total of 453,470 participants, showed a positive correlation between the prevalence of rhinitis and the levels of various pollutants, including PM10, PM2.5, NO2, SO2, and O3, with higher risks identified in children and adolescents than in adults (Li et al., 2022). Interestingly, the impacts of these pollutants were more significant in developing countries, highlighting regional and economic disparities in this association

(Ahmad et al., 2021). (Tran HM et al. 2023)

Geography	Year range	AR Prevalence point 1	AR Prevalence point 2
Finland	1966-2000	0.6%	8.88%
Sweden	1990-2008	21%	31%
United Kingdom	1972/76-1996	5.8%	19.9%
Northern Europe	1990/94-2010/12	19.7%	24.7%
Italy	1985/88-2009/11	16.2%	37.4%
South Korea	2008/09-2016/17	13.5%	17.1%
Western Australia	1981-1990	21.9%	46.7%

Extremes in weather conditions induced by global warming modify pollination patterns and distribution resulting in growth of allergic microbes (mold and fungus), and promotion of allergic rhinitis and asthma exacerbations. Higher humidity has been associated with lower concentrations of some allergens such as tree pollen but increases in others such as mold spores.

About 200 million people worldwide, or approximately 3% of the global population, are estimated to suffer from nonallergic rhinitis (NAR).

Environmental NAR is characterized by nasal hyperreactivity to various environmental triggers, including cold air, tobacco smoke, and chemical products. The hallmark symptoms of NAR are nasal congestion, rhinorrhea, and various pain syndromes, including headaches and atypical facial pain, which are thought to occur through shared neurologic pathways of the sphenopalatine ganglion. As an example of the impact on climate change on NAR related symptoms, results from a recent study of ~10,000 chronic pain sufferers from the United Kingdom demonstrated a direct and significant association between prevalence of pain with low atmospheric pressure, high humidity, high precipitation rate, and stronger wind. (Kim J et al 2022)

3. Chronic Rhinosinusitis/ Sinusitis

CRS affects approximately 5% to 12% of the US population or up to ~ 40 million Americans. Exposure to airborne pollutants including particulate matter (PM), nitrogen dioxide (NO2), and ozone has been shown to contribute to the development and/or exacerbation of several common upper respiratory tract diseases including AR and CRS.

Clinically, long-term air pollution exposure has been found to be associated with the development of CRS in a powered case-control study and a recent systematic review. In addition, air pollutant exposure has been correlated with increased need for revision sinus surgery. Furthermore, US veterans who were exposed to pollutants on deployment overseas have been identified to have a higher prevalence of CRS than a similar cohort of nondeployed veterans. These findings also extend globally to other continents. Urban areas in Cologne, Germany, with above average air pollution levels were associated with higher rates of CRS. Significant correlation between particulate matter exposure and CRS prevalence was found by the South Korean National Health and Nutritional Examination Survey and in a rhinologic outpatient cohort in Xinxiang, China. (Kim J et al 2022)

A recently published study by Patel et al. sought to identify associations between sinonasal histopathology specimens and levels of air pollutants at the patients' place of residence. Within the CRS with nasal polyposis (CRSwNP) cohort, increased inflammation, Charcot-Leyden crystals, and eosinophil aggregates were associated with increased ozone exposure. In fact, for each 1–part per billion (1-ppb) increase in ozone exposure, there was an 81% increased likelihood of having eosinophil aggregates. Climate change has both direct and indirect impacts on air pollutants (relevant for CRS and NAR). (Kim J et al 2022)

4. Flu and flu-like illnesses

Viral respiratory tract infections are most common illnesses in humans, with estimated 17 billion incident cases globally in 2019. Common viruses causing respiratory tract infection include influenza, respiratory syncytial virus (RSV), rhinovirus (RV), and SARS-CoV-2. Viral respiratory infection imposes a substantial burden on populations and health systems. (Burbank AJ et al 2022)

On a molecular level, temperature is known to influence the fusion of viruses with the cellular membranes allowings for cell entry and replication. Viruses cannot efficiently fuse with a cell and inject genetic material at low temperatures. (Sloan C et al 2011)

Short- and long-term exposure to air pollution has been extensively linked with increased susceptibility to respiratory infection. Short-term exposure to increased PM was associated with increased susceptibility to respiratory infections including influenza and influenza-like illness, RSV bronchiolitis, and acute lower respiratory tract infections (LTRI) including pneumonia. Chen et al observed that across 47 Chinese cities, a 10 μg/m3 increase in PM2,5 was associated with an increased risk of influenza (RR 1.020, 95% CI 1.006, 1.034) at lag days 2–3, after controlling for seasonality and weather conditions. Croft et al examined data from 500,000 ED visits and hospitalizations from New York state and found that IQR increases in PM2.5 during the prior week were significantly associated with higher rates of ED visits for influenza (3.9%, 95% CI 2.105.6%; at 7 days) and culture-negative pneumonia (2.5%, 95% CI 1.4–3.6%; at 6 days)

D. Burden of disease

1. Temperature variability and mortality

An increasing trend in temperature variability was identified at the global level from 2000 to 2019. Globally, 1,753,392 deaths (95% CI 1,159,901–2,357,718) were associated with temperature variability per year, accounting for 3.4% (2.2–4.6) of all deaths. Most of Asia, Australia, and New Zealand were observed to have a higher percentage excess in mortality than the global mean. Globally, the percentage excess in mortality increased by about 4.6% (3.7–5.3) per decade. The largest increase occurred in Australia and New Zealand (7.3%, 95% CI 4.3–10.4), followed by Europe (4.4%, 2.2–5.6) and Africa (3.3, 1.9–4.6). (Wu Y et al 2022)

2. Hospitalization and emergency department visits

Extreme weather events were found to be associated with the risk of asthma ED visits, particularly in females. Extreme heat was also observed to be an important risk factor for asthma hospital admissions in the Asia-Pacific and North American regions. A study in the United States observed an increase in the risk of asthma ED visits in children but a decreased risk in the elderly related to extreme weather events. Furthermore, a study conducted in Europe discovered that thunderstorms increased the ratio of asthma symptoms.

Extreme temperature events, including cold spells and heat waves, were observed to be important risk factors for asthma hospital admissions. According to a study in China, cold spells increased the risk of asthma outpatient visits. Moreover, extreme weather events were also observed to be an important risk factor for asthma outpatient visits in the European region by increasing the relative risk by 1.26-fold. Studies in Asia observed that an increase in extreme weather events increased the risk of asthma mortality. A meta-analysis combining 31 studies (until October 2022), taken together, extreme weather events result in increased risks of acute asthma exacerbation events. (Makrufardi F et al 2023)

Asthma outcomes	Risk-ratio (95% CI)	Number of studies
Events	1.18 (1.13-1.24)	31
Symptoms	1.10 (1.03-1.18)	5
Emergency room (ER) visits	1.25 (1.14-1.37)	13
Hospital admission	1.10 (1.14-1.37)	10
Outpatient visit	1.19 (1.06-1.34)	2
Mortality	2.10 (1.35-3.27)	2

ER visits	Risk-ratio
Overall	1.25
Children	1.52
Female	1.31
Male	1.29
Heat-wave	1.18
Thunderstorm	1.23

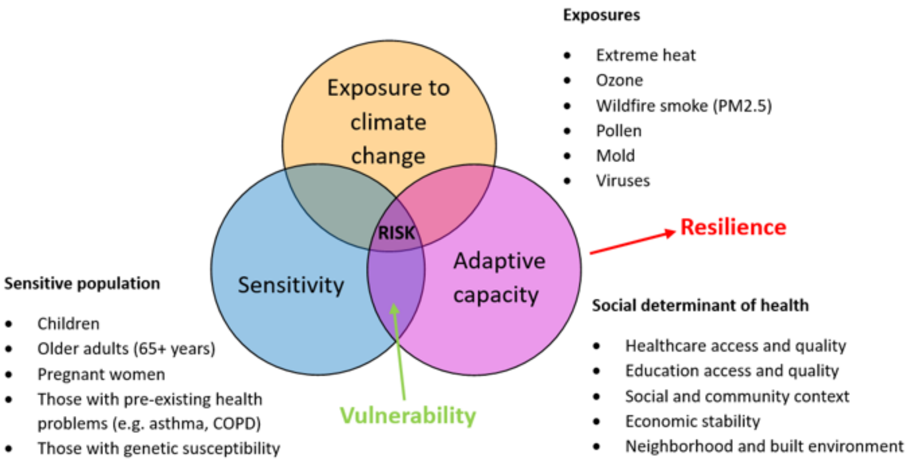
E. Understanding the vulnerable population

People living in poverty or developing countries, communities of color, indigenous groups, racial and ethnic minorities, vulnerable occupational groups, and migrants will bear the brunt of climate change because of their exposure and limited adaptive capacity.

Age, life stage, and health status affect the sensitivity to different climate change–related exposures. Elderly individuals, pregnant women and children, people with disabilities, and those with chronic medical conditions (including immunodeficiency) are at the highest risk.

Considering the fact that impoverished populations have a higher probability of chronic diseases, exposure to environmental pollution can affect individuals with underlying asthma, COPD, and pulmonary fibrosis differentially, putting them at greater risk of hospitalization and mortality, as demonstrated recently in European cities.

Understanding these vulnerable groups' unique challenges is essential for implementing targeted interventions and policies that can effectively mitigate the impact of climate change on respiratory health in these populations.



1. Elderly

In the United States, 40% of all heat-related deaths from 2004 to 2018 were in individuals age 65 years or older. During the 2003 European heat wave, mortality was higher in elderly individuals with underlying respiratory conditions. To put the impact of climate-related changes in perspective, there were **727 million persons aged 65 years or older in 2020, a number that is expected to increase to 1.5 billion in 2050**.

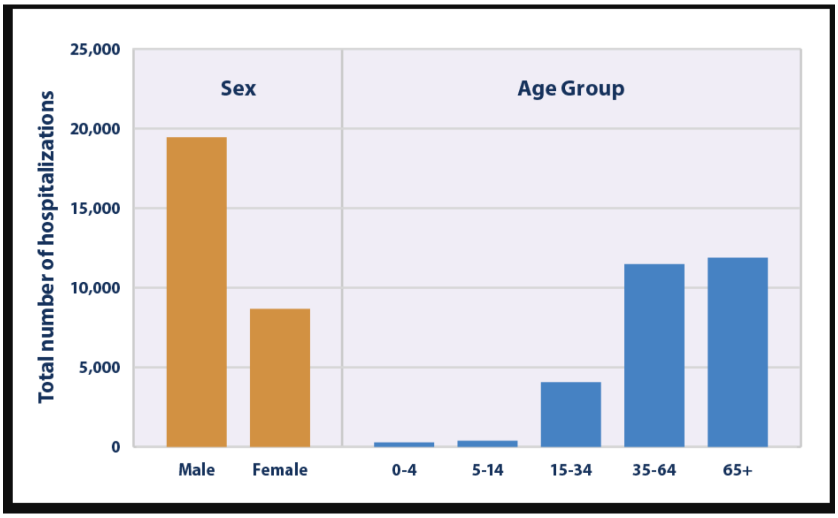
Their physiology, chronic medical conditions, psychological and socioeconomic status, living arrangements, access to care, and limited mobility and transportation increase their vulnerability to heat waves, air pollution, extreme weather events, and infections.

Owing to their extent, exposure to heat and air pollution can be very impactful. Exposure to air pollution PM2.5 and O3, exacerbate underlying medical conditions, including asthma, and increase the mortality of elderly individuals. For example, exposure to PM2.5 has been associated with increased mortality in older or elderly populations, even at levels below those established by the US National Ambient Air Quality Standard.

Other conditions affected by PM2.5 in older adults include respiratory conditions such as asthma and COPD, chronic kidney disease, diabetes, and dementia (including Alzheimer disease).

Heat-induced illness is among the major vulnerabilities for elderly individuals. Variables such as age-related physiologic changes, chronic medical conditions, medications that affect sweating or alertness, disease-related fluid restrictions or limited intake, social isolation, and poverty are among the most common causes of decreased capacity to adapt to changes in temperature. (Pachecho SE et al 2021)

Between 2001 and 2010, people aged 65 and older accounted for more heat-related hospitalizations than any other group. (Source: EPA, Climate Change Indicators in the United States, 2021)



2. Pregnant women

The detrimental impact of the climate crisis on pediatric respiratory health begins before birth, highlighting the inherent vulnerability of pregnant women and children.

Research on outcomes of prenatal exposure to climate change-related environmental changes and pediatric pulmonary health is limited. In addition to adverse pregnancy outcomes known to affect lung development, changes in lung function, increased prevalence of wheezing, atopy, and respiratory infections have been associated with prenatal exposure to increased temperatures, air pollution, and maternal stress. The mechanisms behind these changes are ill-defined, although oxidative stress, impaired placental functioning, and epigenetic modifications have been observed. However, the long-term impact of these changes remains unknown.(Aravind Y et al 2023)

Bekkar B et al 2020, conducted systematic review of 57 of 68 studies including a total of 32, 798, 152 births, there was a statistically significant association between heat, ozone, or fine particulate matter and adverse pregnancy outcomes.

3. Children

Children are a particularly high-risk group on account of their developing organ systems, their higher level of exposure owing to their physiology, the nature of their daily activities, their psychological immaturity, and their dependence on adults.

It is estimated that 88% of the existing global burden of disease attributable to climate change occurs in children younger than 5 years old in both industrialized and developing countries.

Children in the world's poorest countries, where the disease burden is already disproportionately high, are most affected by climate change. Asthma is the most common pediatric chronic disease, affecting 6.8 million, or 9.3% of American children in 2012. (Arpin E et al 2021)

Climate change has been projected to increase childhood asthma via an associated rise in air pollutants, including ground-level ozone. Climate change–associated increase in ground-level ozone may increase child asthma ED visits, with 1 study projecting an increase of 5% to 10% in New York City by 2020.

The 2003 wildfire **in southern California resulted in a 25% higher rate of asthma admissions in 5- to 19-year-olds during the fire and a 56% higher rate after the fires**.

In 2012, 9% of American children suffered from hay fever. The ragweed pollen season in North America has lengthened by 13 to 27 days since 1995 because of delayed first frost and lengthening of the frost-free period, with greater increases in higher latitudes.

4. Those with pre-existing health problems

Those with chronic lung disease (CLD) are likely more vulnerable to extreme heat due to their limited physiologic reserve, age, or simply their decreased ability to access timely medical care in the setting of extreme heat.

During the 2006 heat wave in Europe for example, COPD mortality increased by 5.4% for each 1C increase in mean temperature. Similarly, an analysis of in-hospital mortality in Italy showed that patients with CLD had a more than 2-fold increased odds of death with a 10C increase in ambient outdoor temperature.

Heat stress may lower the threshold for broncho-constriction, and inhalation of dust particles, such as during droughts or dust storms, may interfere with pulmonary endothelial cell signaling. These effects may be accentuated and poorly tolerated in those with CLD. (Shankar HM et al 2020)

5. Urban residents

City dwellers have a greater risk of allergic respiratory diseases because of synergistic exposures of air pollutants, high temperature, and allergens. Keet et al reported that urban residence was independently associated with increased risk of asthma-related emergency department visits and hospitalizations in the US. Migration from rural regions to urban centers is accompanied by increased prevalence rates of asthma. The increased use of fossil fuels in cities contributes to the World Health Organization (WHO) statistic that over 90% of the urban population of the world breathe air that exceeds WHO's air quality guidelines. The urban population will likely be disproportionately affected because of the urban heat island effect since excess heat causes direct impairment on airway and increase the formation of O3. A study from Southern Spain showed that the pollen season in urban areas was twice as long as that of rural environments. (Shi-Zou D et al 2020)

6. Socioeconomic status

With respect to climate change effects on patients with respiratory diseases, special focus should be given to social inequalities, raising awareness of the need for extra efforts to help those most disadvantaged. Climate change is already affecting vulnerable populations disproportionately.

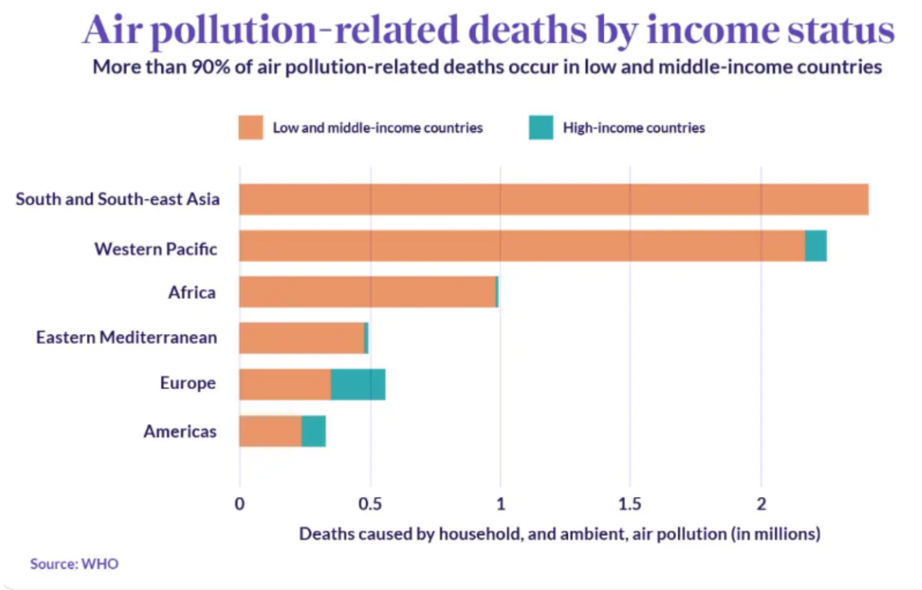
The most socioeconomically disadvantaged groups are less able to mitigate against the various impacts of climate change, in terms of modifications to their lifestyle (cannot afford more climate friendly diets, organic produce), adaption to their dwellings (cannot afford investment in air conditioning, air purifiers, insulation, or flood proofing and extra drainage in their homes), or the ability to move to less impacted locations. (Andersen ZJ et al 2023)

Lower socioeconomic status is also closely related to occupations with higher exposure to heat and aeroallergens, such as construction workers working outside, people working in the agricultural sector, firefighters, *etc.*

Finally, people who are less affluent may have poorer access to good healthcare and medication, and information about risks and how to mitigate them, and are less capable of having the means to manage their respiratory illness and adapt to new climate change related threats, leading to poorer prognosis of their diseases.

This relationship between climate change and social inequality is characterised by a vicious cycle, whereby initial inequality causes the disadvantaged groups to suffer disproportionately from the adverse effects of climate change, resulting in greater subsequent inequality.

These factors impact at both the individual level, within cities and countries, as well as at regional level and between countries. For example, in Europe, where South and South-eastern Europe is more prone to heatwaves and wildfires, and where many countries suffer from higher levels of air pollution and socioeconomic disadvantages than North and Western Europe. This demands special focus on these groups by clinicians, as well as national and city governments in planning of climate mitigation plans. (Andersen ZJ et al 2023)



F. Causality between heating homes in winter and respiratory conditions?

There is a strong correlation between heating homes in winter and the rise in respiratory conditions. When people turn on their heating systems, the air becomes drier, leading to the drying out of nasal passages and throat. This dryness can cause irritation and inflammation, making individuals more susceptible to respiratory infections and conditions such as asthma and bronchitis (Byber K 2021).

WHO Housing and Health Guidelines 2018 strongly recommended that indoor housing temperatures should be high enough to protect residents from the harmful health effects of cold. (WHO housing and health guideline). Cold homes contribute to excess winter mortality and morbidity. **Most of the health burden can be attributed to respiratory and cardiovascular disease**, especially for older people. In children, the excess winter health burden is mostly due to respiratory disease. **Excess winter deaths due to cold housing has been estimated at 38200 per year (12.8/100 000) in 11 selected European countries** (WHO 2011)

A community based, cluster, single blinded randomized study was evaluated to determine whether insulating existing houses increases indoor temperatures and improves occupants' health and wellbeing in 1350 households (4407 participants). Results showed that **insulating existing houses** led to a significantly warmer, drier indoor environment and resulted in **improved self-rated health, self-reported wheezing**, days off school and work, and visits to general practitioners as well as a trend for fewer (although non-significant) hospital admissions for respiratory conditions. (Howden-Chapman P 2007)

A randomized controlled trial was conducted in 409 children aged 6-12 years with doctor diagnosed asthma who resided in five communities in New Zealand. The intervention group installed a non-polluting, more effective home heater before winter. The control group received a replacement heater at the end of the trial. **Non-polluting, more effective heating in the homes of children with asthma did significantly reduce symptoms of asthma, days off school, healthcare utilization, and visits to a pharmacist.** (Howden-Chapman, P 2008)

Effect of heating intervention on daily differences of asthma symptoms and drug use as reported in daily diaries

Variable	No of person days	No of children	Adjusted*	
			Mean ratio† (95% CI)	P value
Lower respiratory tract symptoms	23 475	345	0.77 (0.73 to 0.81)	0.01
Upper respiratory tract symptoms	26 844	360	0.92 (0.74 to 1.14)	0.43

*Adjusted for baseline outcome.
†Average score for intervention group divided by average score for control group.

In another cohort study, using two questionnaire surveys, one before the winter season in November, 2018 and the second after winter in March, 2019 in 155 children who did not use a heating system in the bedroom and 156 children who did. Result showed that heating of bedrooms may have a preventive effect against the onset of colds, flu, and gastroenteritis among children. In addition, heating also reduces absence from school. (Miyake, F 2021)

Association between use of a heating system in the bedroom and disease occurrence compared to non-heating bedroom (Reference) during the follow-up period (from December through February)

Heating system in the bedroom and disease occurrence	**OR**	**95% CI**	**P-value**
Cold ≥ 3 times	0.35	0.19 0.65	0.001
Fever ≥3 days			
Medication due to a cold ≥3 days	0.91	0.87 0.95	<0.001
Hospital visit due to a cold ≥3 times	0.54	0.31 0.94	0.030
Absent from school or nursery due to a cold ≥3 days	0.43	0.27 0.70	0.001
Influenza	0.43	0.26 0.71	0.001

In contrast, Indoor heating systems such as wood stoves, gas water heaters and central heating systems with furnaces and chimneys have the potential to be a source of carbon monoxide poisoning if misused. (Bayhealth, Effects of Dry Winter Air and Indoor Heating on our Respiratory Health, 2023)

The relationship between ambient air pollution and early childhood respiratory morbidity among children whose homes were predominantly heated with coal was examined in a cohort study conducted in an eastern European country from 1994 to 1999. Result revealed much stronger 'pollutant-lower respiratory illnesses (LRI)' associations. The frequency of LRI for particulate matter (PM)2.5, PM10, polycyclic aromatic hydrocarbons (PAHs), and nitrogen oxides (NOX) increased by 84%, 24%, 33%, and 22%, respectively, as three-day average contaminant levels increased within the interquartile range (IQR). (Baker, Rebecca 2004) These results were supported by another study where children exposed to indoor coal combustion experiences a greater incidence of pediatrician diagnosed LRI during the first 3 years of life. (Baker, R 2006)

Bivariable analysis of LRIs in relation to covariates

Covariate/category	No. of events	RR (95% CI)[a]
Heating fuel[b]		
Distance heat + other	427	1.00
Natural gas	198	1.01 (0.73–1.39)
Electricity	59	0.92 (0.52–1.65)
Coal	154	1.56 (1.13–2.15)
Cooking fuel[b]		
Wood	50	1.18 (0.66–2.10)
Electricity	389	1.00
Gas	351	0.92 (0.70–1.22)
Propane	125	1.30 (0.89–1.91)
Coal	11	1.29 (0.26–6.45)
Wood	17	1.20 (0.72–1.99)

[a] RRs and 95% CIs are estimated using GEE models and are adjusted for both sampling design and repeated events.
[b] Assessed at 3-year follow-up.