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Extreme Weather Events and Asthma

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Abstract

Purpose: The objective of this article is to review recent literature on the implications of extreme weather events such as thunderstorms, wildfires, tropical cyclones, freshwater flooding, and temperature extremes in relationship to asthma symptoms.

Methods: PubMed, EMBASE, Scopus, EBSCOhost MEDLINE, and CINAHL literature searches were conducted with librarian assistance for articles about the effect of extreme weather conditions on asthma. Articles were selected for inclusion after the literature search by author review based on topic relevance.

Results: Several studies have shown worsening of asthma symptoms with thunderstorms, wildfires, tropical cyclones, freshwater flooding, and temperature extremes. In particular, thunderstorm asthma can be exacerbated by certain factors such as temperature, precipitation, and allergen sensitization. Wildfire-associated particulate matter and cyclone-related flooding can lead to increased asthma symptoms. Freshwater flooding can lead to increased respiratory infections which can contribute to asthma symptoms. Temperature extremes are associated with asthma exacerbations.

Conclusion: Extreme weather events can have devastating effects on populations and can particularly impact the respiratory health of those with asthma. With climate change and global warming, it is likely the world will continue to experience increased frequencies of these severe events. Therefore, it is imperative that the allergy and immunology community be aware of the health effects associated with these extreme weather events in order to educate patients and engage in mitigation strategies.

Keywords

asthma; extreme weather; thunderstorm asthma; wildfires; tropical cyclones; freshwater flooding; temperature extremes; climate change

INTRODUCTION

Asthmatics make up a population that is particularly vulnerable to serious health impacts from severe and extreme weather events such as thunderstorms, tornadoes, wildfires, droughts, floods, tropical storms, and extremes of temperature, among others. These weather events can drastically affect human health by causing injury, illness, death, as well as

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through socioeconomic impacts ([1]). Previous research has found positive associations with extreme heat/cold events, droughts, wildfires, and floods with negative impacts on human health ([2]). With persistent effects from climate change, it is anticipated we will continue to see increased frequency of extreme climate and weather events which have significant impacts on allergic airway diseases such as asthma ([3]).

Different environmental and social factors have varying degrees of influence on individuals affected by weather and climate changes, with those with chronic health conditions, such as asthma, being particularly sensitive ([1]). Extreme weather changes are capable of affecting airway hyper-responsiveness both directly, such as cold air, or indirectly by increasing aeroallergen levels and worsening air pollution ([4, 5]). Knowledge of these weather events is critical for the allergy and immunology community to adequately address the impacts of affected patient populations. In this article we aim to review recent literature focused specifically on extreme weather events and associated health impacts on asthma. It is essential to increase awareness of these events so identification of potential medical needs of affected populations and improved planning for consequences of these extreme weather events.

THUNDERSTORM ASTHMA

One the most notable but rare extreme weather events with significant impacts on asthma is known as “thunderstorm asthma”. Thunderstorm asthma is a phenomenon where increased frequencies of asthma attacks are observed in geographical areas recently affected by thunderstorm events. These events have been observed in Australia, Saudi Arabia, North America, Iran, UK, Italy, Kuwait, and China ([6]). The exact mechanism is not fully understood and while various theories exist one leading model is accepted as most likely. Namely, the presumed mechanism is excess pollen grains are released in the hours preceding a thunderstorm and undergo rupture due to osmotic swelling or electrostatic charge driven rupture with subsequent release of sub-pollen particles ([7]). These small pollen fragments are then thought to be carried down to ground level within rain droplets or via cold downdrafts/ outflows from thunderstorms ([8]). While typically large grass pollen would have settled in the upper airways, when ruptured into smaller fragments (<3 microns) they are able penetrate deeper into bronchial systems, leading to bronchospasm and asthma exacerbations ([6, 7, 9]).

There are various molecular pathways suspected to be involved in thunderstorm asthma. In previous *in vitro* and *ex vivo* studies it has been shown that allergens, including grass pollen, can prompt secretion of IL-8 from respiratory cells and thus lead to neutrophil recruitment to the airways, worsening asthma ([10, 11, 12]). Additionally, other studies have suggested IL-4 as a potentiator of eosinophilic lung inflammation involved in thunderstorm asthma, as IL-4 causes antibody isotype switching to IgE leading to allergic sensitization ([13, 14]).

To more closely examine weather parameters of thunderstorms associated ER visits for asthma in the United States, Park et al. conducted a study analyzing over 63,000 asthma-related ER visits in Louisiana ([15]). They reported that on days where a thunderstorm occurred, for each 1g/ m^2 /s higher daily precipitation rate, the risk of asthma-related ER visits was increased by 14.5% [Relative rate [RR] 1.145 per 1g/ m^2/s (95% confidence

interval [CI], 1.009–1.300)] ([15]). They also found that on thunderstorm days, for each 1°C lower daily mean temperature, there was an increased risk of asthma-related ER visits by 1.1% [RR = 1.011 per 1°C change (95% CI, 1.000–1.021)] ([15]). They specifically noted these risks to be higher among children and adults under the age of 65 years ([15]). In summary, this study suggested that higher amounts of rainfall and lower temperatures on thunderstorm days may contribute to more asthma attacks and weather forecast data may be helpful in predicting high risk days for thunderstorm asthma ([15]).

Both grass pollen and fungal spores are thought to be implicated in thunderstorm asthma ([16, 6]). Specifically, ryegrass (*Lolium perenne*) pollen sensitization has been suspected as a risk factor for thunderstorm asthma. The two main allergens in ryegrass pollen are Lol p 1 and Lol p 5 and each elicits serum IgE positivity in over 90% of ryegrass pollen sensitive patients ([17]). Hew and colleagues investigated whether ryegrass pollen sensitization had diagnostic utility for predicting risk of thunderstorm asthma ([9]). Specifically, they assessed serum specific IgE levels for ryegrass pollen and for Lol p 1 and Lol p 5 specifically in 60 patients who presented to the ER for asthma during the 2016 Melbourne thunderstorm asthma event ([9]). For comparison they took samples from 19 control individuals with seasonal allergic rhinitis and were outdoors in Melbourne during the thunderstorm but did not develop thunderstorm asthma ([9]). They found that thunderstorm asthma patients had mean Lol p 1 IgE (1.28 μg/mL) levels similar to the control group (1.15 μg/mL), but increased mean levels of ryegrass pollen IgE (51.5 kU/L) and Lol p 5 IgE levels (2.61 μg/mL) vs. controls (16.7 kU/L and 1.7 μg/mL, respectively) ([9]). Based on this data, they suggested that susceptibility to thunderstorm asthma was associated with higher levels of ryegrass pollen (and specifically Lol p 5) IgE sensitization ([9]). The authors concluded that ryegrass pollen IgE levels might be a possible indicator for thunderstorm asthma risk and could potentially be used in the development of risk prediction tools ([9]).

In addition to pollen and fungi, biogenic volatile organic compounds (BVOCs) have been hypothesized to potentially play a role in thunderstorm asthma. In 2019, Gibbs and colleagues investigated the role of plant-related BVOCs on asthma with the hypothesis that increased BVOC emissions may contribute to thunderstorm asthma ([18]). They took 14 volunteers with seasonal asthma and recorded respiratory symptoms, peak expiratory flow levels and collected BVOC concentrations from ambient air from a suburban backyard of a privately owned home ([18]). They found substantially increased levels of BVOCs including linalool (honey fragranced terpene), hexenal (aldehyde sensitizer), and hexanoic acid prior to a thunderstorm ([18]). They also demonstrated that increased levels of linalool predicted increased asthma symptoms including wheeze and dry cough ([18]). The authors concluded that BVOCs may play a role in contributing to thunderstorm asthma, though further studies are warranted ([18]).

In another study Elliot et al. performed an analysis of routinely collected healthcare data in England and focused on June of 2021 where significant increases in healthcare utilization were noted immediately following a period of thunderstorm activity ([19]). On June 16th, 2021 there were several localized thunderstorms categorized as weak to moderate storms that occurred across England ([19]). They analyzed population health impacts on the following day and found that there was a notable spike in asthma symptoms in the areas affected by

these storms ([19]). Specifically, emergency department visits for asthma increased by 560% compared to the expected average from the previous 4 weeks ([19]). Primary care out-of-hours contacts increased by 349% and ambulance calls increased by 54% ([19]). Those between the ages of 5–44 years were the age group most affected ([19]).

Interestingly, these respiratory health impacts in England linked to thunderstorm activity were not as clear as previous episodes as several of the storms which led to increased asthma symptoms were defined as “weak” rather than “severe” storms ([19]). The explanation for this observation was suggested to be driven by strikingly increased levels of grass pollen demonstrated during these storm events ([19]). It was postulated that meteorological conditions (humidity, convergent cross winds, gust fronts) associated with storms were driving events versus specific lightening activity ([19]). Thus, future studies should expand definitions to include not only thunder/lightning storms but “storm” or “severe weather” events to understand the phenomenon of thunderstorm asthma. ([19]).

Along these lines, to examine whether increased pollen levels alone or lightning presence alone may be associated with severe asthma, Smith et al. investigated thunderstorm asthma events in Minnesota from 2007–2018 ([20]). They looked at the risk of severe asthma events at any time thunderstorm asthma conditions occurred, not only during the most severe storms or highest pollen levels ([20]). On the days of thunderstorms (defined as 2 or more lightning strikes) with high pollen counts (>75th percentile) of any type (tree, grass weed) there was a higher risk of asthma-related ED visits (RR = 1.047, CI 1.012–1.083) when compared to days without a thunderstorm asthma event ([20]). In contrast, exposure to lightning strikes in the presence of low pollen levels (<25th percentile) or exposure to high pollen levels without presence of lightning strikes did not demonstrate association with increased severe asthma-related ED visits ([20]). The authors concluded that these results were consistent with the hypothesis that thunderstorm asthma is a unique environmental and health phenomenon associated with co-occurrence of both thunderstorm activity and high pollen levels ([20]).

One of the critical lessons learned from these thunderstorm asthma events is that a significant portion of affected individuals are those without previously known airway disease (potentially up to 60%) ([21, 6]). As seasonal allergic rhinitis and higher ryegrass pollen-specific IgE concentrations are thought to be risk factors for thunderstorm asthma ([21, 6]), allergists are in a unique position to potentially identify patients without a history of asthma who may be at risk for future adverse consequences related to a thunderstorm asthma event. Educating patients on behavioral interventions such as avoiding outdoor exposure in the hours around thunderstorms and monitoring grass pollen counts ([21]) particularly in regards to the seasonal timing of thunderstorm asthma (April through June in USA/Europe/Canada, and October through December in Australia) may help with awareness ([22]). Additionally, allergy immunotherapy and inhibition specific allergic mediators could be considered as potential prevention strategies for thunderstorm asthma, particularly in those sensitive to grass pollens ([6]). Lastly, emphasizing the importance of adherence to inhaled corticosteroids before and during a thunderstorm event can also help at-risk individuals already on these treatments ([6]).

WILDFIRES

Climate change has increased drought conditions which are favorable for the development of wildfires and may result in serious health consequences ([23]). Wildfires generate large amounts of air pollution including greenhouse gases, photochemically reactive compounds, and particulate matter ([24]). We continue to learn more about the health impacts from wildfire smoke exposure but long-term health consequences from such exposures are largely unknown. It is critical to develop an understanding of the health impacts from wildfire smoke exposure on vulnerable populations to effectively mitigate these impacts ([25]).

A study done by Heaney et al. investigated the association between wildfire smoke fine particular matter ($PM_{2.5}$) and cardiorespiratory-related hospital visits during wildfires that occurred between 2004–2009 in California ([26]). They estimated daily mean wildfire-specific fine particulate matter using the Global Fire Emissions Database and defined “smoke event days” as days when the cumulative wildfire-specific $PM_{2.5}$ concentration was ≥ 98th percentile ([26]). It was demonstrated that smoke event days were associated with a 3.3% increase in hospital visits for all respiratory diseases (95% CI, 0.4–6.3%) ([26]). When focused on asthma, smoke event days were associated with a 10.3% increase in hospital visits for asthma (95% CI, 2.3–19.0%) ([26]). They also found that young children aged 0–5 years were most impacted by these health effects ([26]). They concluded that wildfire smoke exposure leads to substantially increased adverse health outcomes in affected populations and more aggressive prevention strategies are warranted ([26]). Thus, improved evacuation plans, proper protective equipment, and statewide guidelines are necessary for future event planning ([26]).

In addition, Beyene at al. examined prolonged wildfire smoke exposure in adults with severe asthma during an intense wildfire period in Australia from 2019 to 2020 ([27]). Participants who had been previously enrolled in an asthma registry completed a questionnaire including asthma symptoms and wildfire exposure ([27]). They found that 83% of the participants had experienced respiratory symptoms including breathlessness, wheeze, and cough during the wildfire period and 44% required oral corticosteroid treatment for an asthma exacerbation during the wildfire ([27]). Following the wildfire, 65% of the participants reported continued asthma symptoms, but they also noted that treatment of asthma with various monoclonal antibody therapies (e.g. mepolizumab, omalizumab or benralizumab) was associated with a reduced risk of persistent symptoms (aRR 0.77, CI 0.60–0.99, p = 0.046) ([27]). It was concluded that wildfire exposure is associated with both acute and persistent respiratory symptoms in asthmatics ([27]).

To determine whether respiratory health impacts due to particulate matter from wildfires differed from health impacts of particulate matter originating from other sources such as transportation or industry, Kiser et al examined frequency of asthma exacerbations in emergency departments and urgent care centers in Reno, Nevada from 2013–2018 in relationship to wildfire smoke and particulate matter levels ([25]). The presence of wildfire smoke increased the association of a 5 $\mu g/m^3$ increase in daily and 3-day averages of $PM_{2.5}$ with asthma visits by 6.1% and 6.8%, respectively ([25]). For PM_{10}, the 5 $\mu g/m^3$ increase in daily and 3-day averages of PM_{10} associated asthma visits was increased by wildfire smoke presence by 5.5% and 7.2%, respectively ([25]). In summary, there were stronger associations

of $PM_{2.5}$ and PM_{10} with asthma emergent/urgent care visits when wildfire smoke was present when compared to non-wildfire PM suggesting that wildfire-related PM may be more harmful for asthmatics than PM from other sources ([25]).

TROPICAL CYCLONES

Due to effects of climate change and global warming, there has been an increased frequency and severity of floods and cyclones ([28]). Model projections predict that global tropical cyclone precipitation rates will increase by 14% with a 2°C increase in mean temperature ([29]). Previous studies have suggested that hurricane exposure has led to increases in self-reported asthma attacks following the hurricane events, as demonstrated by studies of Hurricane Katrina where prevalence of an asthma exacerbation pre-hurricane and post-hurricane were 4.4% and 9.1% respectively ($p < 0.0001$) ([30]). Additionally, increased moisture associated with storms and flooding leads to increased humidity and dampness in the built environment which supports growth of both molds and dust mites, allergens recognized to exacerbate asthma symptoms ([23]).

Ramesh et al. investigated changes in emergency department (ED) visits associated with floods due to Tropical Storm Imelda that occurred in 2019 in southeastern Texas ([31]). They found that during the flood period, ED visits due to asthma had increased by 10% (95% CI: 1–19%) in the flooded areas when compared to non-flooded areas of Texas ([31]). Another study by Lee et al. examined the effects of a tropical storm, Hurricane Maria in Puerto Rico in 2017, on the development of respiratory disease in children in infants that were in utero exposed and conceived at least 5 months after the hurricane ([32]). They examined the nasal microbiome of all the infants and found that infants in the Hurricane Maria exposure group were more likely to have a staphylococcus-streptococcus dominant microbiome when compared to the control group of infants without exposure to Hurricane Maria ([32]). This finding may be at increased risk of asthma because prior studies have suggested that infants with staphylococcus or streptococcus dominant nasal microbiomes have higher risks of asthma ([32, 33]).

FRESHWATER FLOODING

Asthma exacerbations have been linked with flooding events in several previous studies ([5, 34, 35]). Although most of these prior studies link asthma with hurricane-associated flooding events, freshwater flooding may also be associated with asthma due to long-term exposure to mold, fungi, and endotoxins ([36]). In 2021, Larson et al. conducted surveys of households in Detroit, Michigan, whereby recurrent home flooding secondary to storm-water events occur ([36]). They demonstrated that having at least one adult with asthma living in the home was positively associated with a history of flooding (OR 1.42, 95% CI 1.22–1.64) ([36]). Moreover, renters and communities of color were disproportionally impacted by flooding events ([36]).

Another study investigating the effects of freshwater flooding was conducted by Kontowicz et al. in 2022 and focused on the state of Iowa ([37]). Iowa experiences flooding about 20 days of the year which exposes many residents to the negative health effects from flooding

([37]), such as dampness and mold presence which can increase the odds of respiratory infections ([38]). This study aimed to determine the associations between areas with flooding and influenza diagnoses ([37]). While in many hosts influenza leads to only mild infection, for those with chronic lung disease such as asthma, influenza can lead to serious risks such as hospitalization or death. Using de-identified influenza tests from a large private insurance database and the Iowa State Hygienic Lab and established flooding frequency using stream height data from stream gauges, they reported a consistent 1% associated increase in influenza diagnoses per day of flooding (95% CI, 1.00–1.04) ([37]). The greatest risks were seen in the most densely populated areas of Iowa ([37]). The authors postulated that if there were to be a widespread flooding event in the state (as seen in 2010), there could be an additional 31,555 influenza diagnoses in Iowa for each day of flooding ([37]). Therefore, it was suggested that populations exposed to flooded areas consider taking measures to avoid environmental exposures in order to reduce possible health consequences from influenza ([37]).

EXTREMES OF TEMPERATURE

Non-optimum ambient temperature (more simply known as low and high temperatures) is a known risk factor for premature death and there is growing evidence that it may also play a role in exacerbating asthma. Unfortunately, there are limited studies and the effects of temperature on asthma are inconsistently described ([39, 40]). A recent study conducted in China where nearly 5,000 adult asthmatics were tracked from 2017 to 2020 and associations between daily pulmonary function tests (PFTs) and ambient temperature were assessed ([39]). They found that when temperatures were elevated there was a statistically significant decrease in forced expiratory volume in one second (FEV_1) by 26 mL (95% CI: 4.9–47, $p< 0.05$) ([39]). The effects on lung function of the extreme high temperatures were noted to occur at around 24 hours after the peak temperature and could persist until 72 hours after the peak ([39]). In contrast, the effects from extreme low temperatures were noted to onset at time 0 hours and could also last until 72 hours post-exposure ([39]). Extreme low temperatures were associated with statistically significant decreases in FEV_1 of 60.4 mL (95% CI, 38.1–82.7, $p<0.05$) and 101.5 mL in forced vital capacity (FVC) (95% CI, 66.3–136.6, $p<0.05$) ([39]). This study suggests that both ends of temperature extremes can have adverse health impacts for asthmatics, but the effects of low temperature may be more deleterious ([39]).

A systematic meta-analysis (37 articles) review was conducted by Han et al. in 2022 to further assess the impacts of extreme heat and cold on asthma ([40]).Results demonstrated that the relative risk for an asthma exacerbation in extreme heat was 1.07 (95% CI, 1.03–1.12) and in extreme cold was 1.20 (95% CI, 1.12–1.29) ([40]). Therefore, this study further supports the role of extreme heat and extreme cold negatively impacting respiratory health consequences in asthma, with greater potential risks with extreme cold conditions. However, in a literature review focused on the effects of ambient extreme heat and morbidity outcomes of pediatric populations, Uibel et al. in 2022 highlighted 4 studies from 2016–2019 demonstrating positive associations between asthma/wheeze morbidity and high temperature exposures ([41]).

CONCLUSION

With climate change and global warming concerns it can be anticipated that the world will continue to experience increased amounts of outdoor air pollution, increased pollen exposure and increased frequencies of extreme weather events as discussed in this article ([23]) with summary of asthma effects in Figure 1. These events can have devastating effects on communities and impact the respiratory health of affected populations, particularly those with asthma. Additionally, extreme weather events and their health effects disproportionately affect disadvantaged and lower socioeconomic populations ([23]). The allergy and immunology community must be aware of the negative health effects of climate change associated extreme weather events in order to adequately educate patients about health risks and engage in mitigation strategies to help reduce the potential adverse consequences. Additionally, asthma health care providers have responsibility to advocate for our patients with respect to policies which could have significant impacts on possible climate solutions and potentially reduce the number or severity of extreme weather events.

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Clinics Care Points

- Thunderstorm asthma is a phenomenon where increased frequencies of asthma exacerbations are seen in areas recently affected by thunderstorm events. This type of asthma exacerbation can be worsened by increased precipitation and lower temperature during the event. It can also be worsened by ryegrass pollen sensitization.
- Wildfires generate large amounts of air pollution and wildfire-associated particulate matter has been found to exacerbate asthma more than non-wildfire associated particulate matter.
- Tropical cyclones can lead to subsequent flooding events which contribute humidity and dampness and worsen asthma symptoms. Additionally, the post-cyclone environment has been found to lead to alterations in infant nasal microbiomes and may predispose to asthma development later in life.
- Freshwater flooding can lead to an increased risk of influenza diagnosis and therefore could contribute to viral infections that lead to asthma exacerbations.
- Temperature extremes, such as both high and low temperatures, have been found to be associated with a reduction in FEV_1 and asthma exacerbations.

Thunderstorm Asthma 	• Worsened by increased precipitations ([15]) • Worsened by lower temperature ([15]) • Worsened by ryegrass pollen sensitization ([9])
Wildfires 	• Wildfire associated particulate matter is worse for asthmatics than non-wildfire associated particulate matter ([25]) • Treatment with monoclonal antibodies is protective for asthmatics with wildfire exposure ([27])
Tropical Cyclones 	• Cyclone-related flooding worsens asthma symptoms ([31]) • Post-cyclone environment alters infant nasal microbiome and may predispose to asthma ([32, 33])
Freshwater Flooding 	• Freshwater flooding increases risk of influenza diagnoses ([37]) which can exacerbate asthma
Temperature Extremes 	• Low temperatures are associated with reduced FEV_1/FVC and asthma exacerbations ([39, 40]) • High temperatures are associated with reduced FEV_1 and asthma exacerbations ([39, 40])

Figure 1. Summary of asthma effects associated with severe weather events.

Asthma symptoms can be affected by various weather events including thunderstorms, wildfires, tropical cyclones, freshwater flooding, and temperature extremes. Figure created with BioRender.com.