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PROTECTING CHILDREN'S HEALTH: ASTHMA AND CLIMATE CHANGE

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Abstract
Children are particularly vulnerable to the impacts of climate change. Their lungs are developing, making children with asthma especially susceptible to temperature extremes, variations in precipitation, poor air quality, and changes in pollen and flora. Structural and social determinants of health, such as racism and poverty, that disproportionately affect children of color are linked to higher rates of asthma and negative effects of climate change. These factors lead to increased absences from school and social activities, loss of work for caregivers, and increased health care costs, thus negatively affecting children, their families, and the greater community. Nurses must support caregivers and children to link climate change to asthma care, be involved in health education; climate change mitigation and adaptation strategies and policies; and develop the evidence to address climate change and asthma strategies. We address the impacts of climate change on children with asthma and nursing adaptation responses.

Key words: Asthma; Child health; Climate change; Environmental health; Maternal–child nursing.

Children have unique needs related to their interaction with the environment. Children's metabolisms are different, their bodies continue to develop throughout childhood, and they depend on others for safe social and physical environments (American Academy of Pediatrics Council on Environmental Health [AAPCEH], 2019a). Children breathe in more air per their body weight and they spend more time outdoors than adults (AAPCEH, 2019b). This makes a child's response to environmental toxicants different than adults and the environmental exposures that occur in childhood could influence an individual's health into adulthood. The impacts of climate change on children with asthma and nursing climate change adaptation responses are presented.

Children's lungs grow and mature after birth, with the number of alveoli increasing through the age of 2 years old (AAPCEH, 2019b). The lungs continue to grow as the child grows. Because their airways are smaller, the slightest amount of inflammation leads to a greater proportion of airway constriction (AAPCEH, 2019b). Exposure to air pollution during childhood can interfere with critical lung development and can lead to inflammation of the airways and asthma exacerbations (Wu et al., 2022).

Asthma is a chronic disease of the respiratory tract characterized by airway inflammation, bronchial hyperresponsiveness, and intermittent reversible airway obstruction (AAPCEH, 2019a). Environmental and genetic factors play a role in asthma etiology. Prenatal and early life exposures can contribute to asthma (AAPCEH, 2019a; Wu et al., 2022). Asthma is the most common childhood respiratory disease and the leading cause of emergency department (ED) visits (Patel & Teach, 2019). It is the primary reason for school absences in children ages 5 to 17 years old, causing 13.8 million missed school days nationally (Centers for Disease Control and Prevention [CDC], 2015). Asthma hospitalizations, ED visits, treatments, school absences, and caregivers' missed work cost more than $80 billion annually in the United States (Patel & Teach, 2019).

According to the Asthma and Allergy Foundation of America (AAFA, 2022), approximately 7.5 million children (0–18 years old) in the United States are diagnosed with asthma; with 1 in 12 children having asthma (Patel & Teach, 2019). Black children are three times more likely to have asthma than White children. Asthma is more common in male children (8.4%) than females (5.5%; AAFA, 2022).

Asthma and asthma exacerbations are influenced by environmental factors, such as temperature extremes, variations in precipitation, air pollution, and changes in pollen and flora (George et al., 2017). Social determinants of health, such as inferior housing, densely populated housing, access to health care, and education of the child's caregivers, are associated with a child being diagnosed with asthma and receiving appropriate and timely treatment (Khan et al., 2021; Patel & Teach, 2019).

Influence of Climate Change on Children's Health

Climate change occurs from atmospheric trapping of the sun's heat and projecting the heat back to Earth. The heat-trapping occurs from a build-up of greenhouse gases (GHGs) such as carbon dioxide, methane, nitrous oxide, and fluorinated gases in the atmosphere. Human generation of GHGs, the leading driver of climate change, is primarily from burning fossil fuels (gas, oil, coal) for transportation, energy and industry, agricultural practices, and deforestation (Intergovernmental Panel on Climate Change, 2021). Climate change is responsible for increased frequency and intensity of weather events such as extremes in temperatures and precipitation, poor air quality, and changes in pollen and flora. These changes influence human health.

Children under 5 years old are particularly vulnerable to the impacts of climate change due to their rapid respiratory rates, developing respiratory and immunological systems, and smaller airways (Di Cicco et al., 2020; O'Lenick et al., 2017). Heatwaves can place children at risk because their thermoregulation capacity to maintain their internal body temperature is still developing (O'Lenick et al., 2017). These environmental changes and the child's developing bodies put children with asthma at risk for exacerbations (D'Amato et al., 2018; Di Cicco et al., 2020) and reverse decades-long progress that has been made toward childhood well-being and survival (Helldén et al., 2021).

Extremes of Temperatures

Extremes of temperatures frequently occur as a result of climate change. Although extreme heat is more commonly experienced, extreme cold events can also occur because of Arctic warming and the weakening of the jet streams, allowing frigid air to dip into typically more temperate regions (Cohen et al., 2021). Rapid or extreme weather changes are asthma triggers that can induce asthma exacerbations (Helldén et al., 2021; Patel & Teach, 2019) and can increase the risks of childhood asthma hospitalizations (Shoraka et al., 2019). Prolonged periods of heat, as experienced during heatwaves, can lead to systemic inflammation and increased core body temperature, with decreased cardiac output, tidal volume, respiratory rate, and pulmonary ventilation, making children with asthma at risk of exacerbations and hospitalizations (O'Lenick et al., 2017). Increased ED visits and hospitalizations occur once there has been several days of heat (Di Cicco et al., 2020). Heat stress leads to dehydration that can disrupt pulmonary perfusion (Demain, 2018).

Cold temperatures can also be problematic for children with asthma. Cong et al. (2017) found an association between rapidly lowering temperature and an increased risk of asthma exacerbations. Changes in weather conditions, especially high relative humidity and cold weather, were associated with asthma attacks in younger children (Yousif & Al Muhyi, 2019). Rising humidity, because of climate change, is a problem for indoor air quality, as more indoor moisture can lead to mold, a known asthma trigger (Sly & Holt, 2018). However, in a subtropical region of China, low humidity and lower temperatures, measured by humidex, were correlated with more asthma hospitalizations, and girls were more frequently affected (Pan et al., 2019).

Response to climate change-related heat is noted to be influenced by health care access, race and ethnicity, and economic status. Children are especially vulnerable to these impacts because they depend on adults for support, and this reduces their ability to adapt to heat (Xu, 2018). Specifically, poverty related to poor education, race and ethnicity, and health insurance was linked to heat vulnerabilities for children with asthma (O'Lenick et al., 2017). To compound matters, children in schools that were not air-conditioned were found to have a 1% decrease in learning for every degree Fahrenheit increase in temperature, further increasing the learning gap for low-income children attending schools that cannot afford air conditioning (Park et al., 2020).

Variations in Precipitation

The impact of climate change across the United States related to precipitation varies from very dry to very wet. Warmer temperatures promote evaporation that leads to the drying of water sources, soil, and vegetation. Higher temperatures reduce rainfall and add to drought conditions and wildfire risks. Periods of drought are associated with increased mortality of children 5 to 15 years old (Di Cicco et al., 2020). Droughts also disrupt the local ecosystem and shift families into poverty and forced migration (Helldén et al., 2021); thus, disrupting health care services and stressing the health and well-being of children and familial stability.

There is early evidence that hot, drying temperatures decrease the humidity and increase elevated particulate matter resulting in a heightened risk of mortality and morbidity (Helldén et al., 2021). Regions that experience low humidity reported higher rates of asthma admissions for children, with girls being more sensitive to low humidity conditions than boys (Pan et al., 2020). Conversely, regions with more humid weather have increased risk of indoor mold and fungal spores (Helldén et al., 2021). Intensive rain and flooding can induce residential dampness and mold proliferation, thus influencing indoor air quality and asthma exacerbations (Eguiluz-Gracia et al., 2020).

Air Pollution

Ground-level ozone is an asthma trigger as it can cause a decrease in lung function and inflammation (Nassikas et al., 2020; Wu et al., 2022). Warmer ambient temperatures, from climate change, along with photochemical reactions with volatile organic compounds (VOCs), carbon monoxide (CO), and nitrogen oxides (NOx) promote the production of ground-level ozone. Elevated ozone levels are frequently a problem in urban areas from the combustion by motor vehicles and industry that generate VOCs, CO, and NOx. However, there are instances where elevated ozone levels have been observed in rural agricultural areas. Increases in ozone are projected to increase pediatric ED visits (Sheffield et al., 2011). Without climate change mitigation and reduction of GHG emissions, ozone concentrations are expected to contribute to approximately 84,000 asthma ED visits annually, with the estimated cost from $45 million to $156 million U.S. dollars a year for all age groups. Children ages 5 to 18 experience the most significant benefit of ozone reductions from climate change mitigation efforts (Nassika et al., 2020).

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Nurses play an important role in caregiver and child education on the relationship between climate change and asthma including tracking weather patterns, ambient air quality, and assessing indoor triggers.

Fine particulate matter ($PM_{2.5}$) air pollution is responsible for developing asthma and asthma exacerbations (Nassikas et al., 2022). Rising $PM_{2.5}$ levels from climate change are projected to lead to 38,000 new cases of childhood asthma, and 29 million additional albuterol inhaler uses per year in the United States by 2030 (Nassikas et al., 2022). Unfortunately, the propellants used in metered dose inhalers, such as albuterol, contribute to the health sector's greenhouse gas emissions (Wilkinson & Woodcock, 2022). Increased particulate matter (PM) will worsen with climate change-related events such as fires, droughts, and sandstorms (Helldén et al., 2021). Risks of these events are compounded by warmer temperatures and drought conditions that can lead to wildfires and consequently increase airborne particulates (Demain, 2018).

Fine particulate ($PM_{2.5}$) exposure is associated with preterm birth (Alman et al., 2019), and air pollution can interfere with children's lung development (Wang et al., 2020). $PM_{2.5}$ exposure has been found to reduce the lung function of children's developing lungs (Eguiluz-Gracia et al., 2020; Helldén et al., 2021). McGeachie et al. (2016) found that NOx, nitrogen dioxide, and $PM_{2.5}$ were associated with worsening lung function measured by decreased forced expiratory volume in one second (FEV_1). The combination of heat and elevated air pollution causes bronchial inflammation and decreased threshold for bronchoconstriction (Demain, 2018). This has led to an increase in ED visits for children with asthma (Helldén et al., 2021).

Dust is an asthma trigger. Climate change has increased the presence of dust storms across the globe. These events are typically caused by intense winds from a thunderstorm

that generates a wall of dust over a region (National Oceanic and Atmospheric Administration, n.d.). Dry conditions from climate change in North America have led to more dust storms that aggravate the children's respiratory tracts. Arizona, California, Nevada, and Washington are the states with the most frequent dust storms in the United States. The storms typically occur in the spring and summer, with July having the highest number (Schweitzer et al., 2018). Dust particles can consist of minerals from rocks, pathogens, pollen, dust mites, fungal spores, and anthropogenic pollutants such as heavy metals, pesticides, and polycyclic aromatic carbons (Schweitzer et al., 2018). The dust can travel thousands of miles over several days and remain in the air locally for as long as 3 days following the storm. As a result, dust storms have been associated with increased asthma prevalence and pediatric ED visits and hospitalizations (Schweitzer et al., 2018).

Pollen and Flora

Climate change has increased the concentration and seasonality of aeroallergens (Helldén et al., 2021). Aeroallergens are any type of airborne allergen, such as pollens and spores. Pollen is a documented childhood asthma trigger (Xu, 2018). Since 1990, the pollen season has increased by 20 days and contains 21% more pollen (Anderegg et al., 2021). Aeroallergens promote inflammation of the respiratory tract for those who are allergic, making children at greater risk of asthma exacerbations (D'Amato et al., 2018). Di Cicco et al. (2022) found an increase in asthma hospitalization for children with asthma or asthma-like symptoms when exposed to outdoor allergens such as pollen. Children were noted to have respiratory symptoms at least 2 days before being hospitalized; boys and children older than 5 years were more frequently hospitalized (Di Cicco et al., 2022).

In the presence of air pollution, pollen can oxidize and break down into smaller inhalable particles. Pollen from birch, ragweed, and hornbeam raises allergic and inflammatory responses (Eguiluz-Gracia et al., 2020). The combination of pollen season and thunderstorms is associated with a phenomenon known as "thunderstorm asthma." Thunderstorms can concentrate pollen grains at ground level and release allergic pollen that is an inhalable size during the first 20 to 30 minutes of a thunderstorm (D'Amato et al., 2018). Heat stress promotes airway inflammation and lowers the airway hyperreactivity threshold, and pollen is enhanced in the presence of heat (Demain, 2018).

The changing climate has led to a loss of biodiversity, which has influenced the environment and available food sources with resultant changes in the respiratory microbiome, the bacterial environment of the respiratory tract. These alterations are linked to inflammation and worsening asthma symptoms (Wypych et al., 2019). Additionally, changes in the availability and nutritional value of food from rising carbon dioxide levels could make food more immunogenic, leading to food allergies and increased risk of asthma and disease severity (Wright, 2020).

Nursing Response

To protect children's health, nurses must learn about climate change, understand its implications for nursing practice, advocate for health-protective climate change policies, and rely on the current scientific evidence to inform practice (Chaiard & Turale, 2022). Nurses must also contribute to the scientific knowledge necessary to address the needs of children with asthma in the era of climate change. An evidence-based, interdisciplinary approach could reduce pediatric asthma exacerbations and hospitalizations.

Practice

Nurses must provide basic, age-appropriate, asthma education to children and their caregivers, including climate change's impact on children's health (Di Cicco et al., 2020). Anticipatory guidance to reduce asthma triggers and exacerbations is essential in asthma education. Asthma care in the era of climate change must also include tracking weather patterns, ambient air quality, assessing indoor triggers, addressing health literacy, and an asthma action plan that includes understanding asthma triggers, pharmacological management, and indications and uses of rescue medications (Xue et al., 2022).

To support child and caregiver decision-making to prevent asthma exacerbations, there are free online resources, many of which can be downloaded to mobile devices (see Table 1). AirNow (AirNow.gov) provides real-time and next-day forecasts of particulate matter ($PM_{2.5}$ & PM_{10}) and ozone. Smoke and wildfire maps, health information that includes activity guides for ozone and particulates, and guides for schools related to air

TABLE 1. WEB-BASED RESOURCES TO ADDRESS CLIMATE CHANGE AND ASTHMA

Organization	Title and Information	Website
Environmental Protection Agency	AirNow: real-time and next day particulate matter, ozone, smoke, and wildfire	https://www.airnow.gov
National Weather Service	Real-time forecast of weather and air quaintly, including dust	https://www.weather.gov/
Pediatric Environmental Health Specialty Units	PEHSU: 10 US regional PEHSUs can educate nurses and community regarding asthma and climate change as well as other environmental health issues	https://www.pehsu.net/
The Weather Channel	Detailed information about pollen, including the pollen count, pollen size, and source of pollen in one's community	https://weather.com/

quality can be downloaded from AirNow site to share with caregivers. There are also web-based asthma management applications (apps) that can link environmental conditions, such as ambient air quality, weather, and temperature, to asthma symptoms and medication/inhaler use (Himes et al., 2019). The national network of Pediatric Environmental Health Specially Units (PEHSUs; https://www.pehsu.net/) can support nurses in addressing childhood asthma related to climate change and other environmental exposures.

The National Weather Service (https://www.weather.gov/) provides real-time forecasts about the weather and air quality, including dust. The Weather Channel (https://weather.com/) has detailed information about pollen, including the pollen count, pollen size, and source of pollen in one's community. If someone does not have access to the internet, this information can also be found in a local daily newspaper. Children and caregivers should be encouraged to use this information when planning outdoor activities to assess the need for rescue medication, and if outside protective masks are necessary when air quality is in the harmful range (Di Cicco et al., 2020).

School nurses or nurses working with community organizations can be vital in addressing climate change and asthma triggers for their communities. One way to do this is through the Environmental Protection Agency's (EPA) Air Flag Program (AirNow, 2020). This program provides the school or organization with flags that match the EPA's color-coded air quality index (AQI). The organization is instructed to check the AQI each morning and raise the corresponding color flag. This can alert children and their caregivers of asthma risk. The EPA Air Quality Flag Program can be an opportunity to talk about air pollution, its causes, and its relationship to climate change and childhood asthma with caregivers.

Advocacy and Policy

Nurses must consider the various policies that influence climate change and children's asthma. While addressing air quality, nurses are also addressing the factors that promote GHG emissions, protecting children's developing lungs, and preventing asthma exacerbations. Earlier policies, such as restricting cigarette smoking in public places and the Clean Air Act, have positively affected air quality and health. Supporting policies that promote active transportation, such as walking and biking paths, in communities can improve local air quality and improve mental and physical health (Eguiluz-Gracia et al., 2020). Reduced GHG emissions can be achieved with the use of electric vehicles, public transportation, and safe walking and bike pathways. Although it may not be popular, Eguiluz-Gracia et al. (2020) recommended making the use of motor vehicles more costly to encourage fewer polluting forms of transportation.

To support school students' learning, nurses must advocate for climate adaptation strategies such as energy-efficient air conditioning in schools in regions that experience extreme heat events. Also, when selecting plants in public areas, nurses should advocate to avoid trees, such as birch trees, that could impact the pollen count on sensitive groups. The nurse could encourage community members to engage a tree expert to select trees that provide shade while producing minimum pollen.

There are federal programs that nurses can use to support or scale to reach other constituencies. Traditional school buses currently in use are responsible for increased local PM from diesel exhaust (Li et al., 2009) and children riding older school buses have been found to be exposed to diesel emissions while riding the bus (Marshall & Behrentz, 2005). Part of the 2021 American Rescue Plan included $7 million for low-income, school districts to convert the fleet from diesel-powered to electric school buses (EPA, 2021). This program was expanded in 2022 with the EPA's Clean School Bus Program, which will provide $5 billion through 2026 to replace the current school bus fleet with zero-emission and low-emission buses (EPA, 2022). These programs are examples of effective policies addressing climate change mitigation while reducing local air pollution affecting children's health.

Research

There are many research questions related to childhood asthma and climate change that need to be addressed. Nurse scientists should investigate effective communication about our changing climate, its effects, and asthma management for caregivers and children of different ages. Understanding effective patient education related to climate change and asthma care is also an important area of study. It is essential to understand what makes caregivers and children motivated to take action to mitigate or adapt to climate change impacts. There are also opportunities to include older children in climate change and asthma research to enhance children's engagement and scientific understanding.

Nurse scientists should collaborate with other researchers, such as environmental scientists, to study the metrological impacts of a changing climate on children with asthma. There is a research gap on the effects of weather extremes on childhood asthma and asthma management interventions that could be illuminated by collaborative nursing research. There is need to investigate the influence of humidity on childhood asthma. Longitudinal studies could provide insight into childhood development and asthma symptoms through various climate change events. Collaboration with a microbiologist to study the effect of climate change upon the respiratory microbiome upon children's respiratory health would also be valuable.

Conclusion

Climate change affects air quality, ambient temperature, pollen, and flora. These changes create a complex series of health risks for children with asthma. Nurses must understand the effects of climate change on the local environment and how those changes influence childhood asthma. With that knowledge, the nurse must educate caregivers and children with asthma about the impacts of

CLINICAL IMPLICATIONS

Nurses working with children with asthma must:

- Learn the relationship between climate change, children's respiratory health, and asthma management.
- Educate caregivers and children of the relationship between climate change and asthma that includes tracking weather patterns, ambient air quality, and assessing indoor triggers.
- Encourage the use of current real-time resources to modify plans based on air quality and weather conditions.
- Support policies that promote healthy environments, such as active transportation, electric school buses, energy-efficient air conditioning, and low-pollen plants.
- Engage in nursing and interdisciplinary research related to climate change motivation for action and asthma interventions.

climate change on their health. Nurses must advocate for effective local and federal policies that support climate change mitigation and adaptation. Rigorous climate change research that links the impacts of climate change on the health of children with asthma can advance the care of childhood asthma. ✣

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