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Climate change-associated health impacts: a way forward

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An Editorial on the Frontiers in Science Lead Article
Immune-mediated disease caused by climate change-associated environmental hazards: mitigation and adaptation

Key points

- Climate change is inextricably linked with worsening planetary and human health, necessitating a global multidisciplinary effort to identify the cumulative human health risks to help predict, prevent, and manage future impacts.
- The development of climate change mitigation strategies with co-health benefits will require many technological and policy changes across multiple sectors, with the public health and healthcare delivery sectors playing a major role.
- Evidence-based climate mitigation strategies that are equitable, adoptable, sustainable, and economically feasible are urgently needed to reduce the impact of climate change on health.

Introduction: climate change threats to human health

Climate change is the greatest threat to human health and well-being that humanity has ever faced. Human activities are driving increases in the levels of atmospheric heat-trapping greenhouse gases (GHGs, i.e., carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons), resulting in substantial increases in global temperatures. The rise of global temperatures is already causing widespread ecological changes, including increased frequency and severity of extreme weather events (heatwaves, wildfires, floods, and droughts), rising sea levels, and seasonal shifts in plant and animal geographic ranges and growing seasons that disrupt and endanger the health and lives of many (1). Left unchecked, climate change-related ecological impacts will worsen and threaten the very existence of humankind by affecting the air we breathe, the food we eat, and the water we drink. Thus, it is imperative that we take steps to prevent further loss of life associated with fossil fuel-related emissions.

In their lead article, Agache and colleagues (2) summarize the myriad of impacts of climate-related changes on physical health—including respiratory and allergic disorders, heat-related deaths, cancer, food- and waterborne infectious diseases, zoonotic diseases, and malnutrition—and mental health. As they point out, one of the strongest links between climate change and health is the direct effect of exposure to fossil fuel combustion products [e.g., particulate matter ($PM_{2.5}$), nitrogen oxides, and sulfur dioxide]. The World Health Organization (WHO) estimates that air pollution kills approximately 7 million people worldwide every year (3). Although major improvements in air quality have been made in the United States over recent decades, exposure to high levels of air pollution remains a threat to human health across much of the globe. Unfortunately, climate change-related extreme weather events (e.g., wildfires) are reversing some of the gains in air quality that have been achieved in some areas, while exacerbating already high levels in other parts of the world.

Exposure to ambient $PM_{2.5}$ is the leading risk factor for disease globally. $PM_{2.5}$ exposure is well documented to promote the development of cardiovascular risk factors such as hypertension and atherosclerosis, and as increasing the risk of cardiovascular diseases, including myocardial infarction, stroke, heart failure, and arrhythmias. It is also associated with lower respiratory tract infections, lung cancer, and diabetes. However, the best-documented link between exposure to fossil fuel emissions and disease morbidity and mortality is the exacerbation of respiratory disorders such as asthma and chronic obstructive pulmonary disease (COPD). Global warming worsens respiratory diseases in several ways. For example, it increases ozone levels and the quantity and duration of airborne aeroallergens produced. It also increases the molecular allergenicity of pollens and changes their distribution. Strikingly, fossil fuel-driven increases in both temperatures and carbon dioxide levels have dramatically increased the quantity of allergy-inducing pollen produced and the length of the pollen season. Moreover, severe weather events such as thunderstorms increase the level of dispersion of respirable pollens—triggering acute asthma attacks and, in some cases, death. Cumulatively, these global warming effects will extend the suffering of individuals with hay fever and increase the frequency and severity of asthma attacks.

Synergistic pollutant and climate change-induced epithelial barrier function disruption

Agache et al. propose epithelial injury as the common mechanism linking climate-mediated ecological changes with the worsening of immune-mediated diseases. The epithelial lining of several organs, including the lungs, gastrointestinal tract, and skin, protects these organs against damage from external stimuli. This lining acts as a sentinel to alert the immune system to potential invaders or exposure to toxic substances through oxidative stress responses and the release of innate immune mediators that activate the adaptive immune system to mount a defense. For example, exposure to pollutants resulting from fossil fuel emissions and wildfires (e.g., $PM_{2.5}$, smoke, and chemicals) triggers oxidative stress responses and the release of innate immune mediators such as complement factor 3 (C3), which recruits both inflammatory cells and cells of the adaptive immune response, e.g., CD4+ T cells (4). Saunders et al. (5) showed that exposure of mice to ambient levels of $PM_{2.5}$ alone induced allergic asthma symptoms through a CD4+ T cell-dependent mechanism. Similar scenarios are likely to occur at the gut and skin barriers.

The impact of climate-related increases in exposure to air pollutants on allergic airway disease is compounded by several factors. These include a concomitant increase in dust mites and molds, and the development of an increasingly chemical world, which is awash with pesticides, detergents, plastics, and endocrine disruptors—2000 new commercial chemicals are released annually in the United States alone. In parallel, climate-mediated disturbances in our microbial ecosystem will synergistically worsen our ability to respond. The cumulative health consequences associated with our changing exposome will be preferentially borne by those who are most vulnerable, including the elderly, pregnant women, children, those with pre-existing diseases, and those of low socioeconomic status. Allergic disorders and asthma are already the most common chronic disorders of childhood. Recent studies show that maternal exposure to even low levels of $PM_{2.5}$ is associated with intrauterine inflammation, which has been linked to several adverse birth outcomes (6), suggesting that exposure to these pollutants may have lifelong health effects. Exposure to fossil fuel emissions has also been linked to increased incidences of lung, breast, and colorectal cancers together with poorer survival rates. In common with its effects on respiratory diseases, $PM_{2.5}$ exposure is postulated to cause local tissue inflammation leading to oxidative stress and epigenetic changes that collectively create a permissive environment for cancer development. Similar processes may also promote autoimmune disorders, but more studies are required to firmly establish these links. Understanding the environmental underpinnings of various cancers, autoimmune conditions, and other immune-associated diseases would greatly enhance our understanding of disease susceptibility and may lead to the development of sorely needed prevention and treatment strategies for these debilitating disorders.

Identifying the full effect of climate change on health will require a global, multipronged, multidisciplinary approach in which scientists from all disciplines (including medicine, public health, biology, earth science, climate science, and data science) will need to lend their expertise to assess the individual and cumulative as well as past and current impacts of climate change on health—enabling the prediction of future consequences and the implementation of effective prevention and treatment strategies. Emerging capabilities in data science, artificial intelligence, and advanced biomedical monitoring and screening techniques must be leveraged to untangle the complex web of climate-induced health effects.

The need for effective and implementable mitigation and adaptation strategies

Given the multitude of climate change drivers, addressing the GHG mitigation challenge will require many technological and policy changes across multiple sectors. Agache et al. summarize the implementable and economically sound evidence- and equity-based strategies needed to reduce the impact of climate change on health, and they highlight the need for buy-in and cooperation among governments, industries, communities, individuals, and healthcare providers (2). They emphasize the need to reduce fossil fuel emissions and improve air quality, provide safe housing (e.g., improving weatherization) and green spaces, improve diets, adopt sustainable agricultural practices, and increase environmental biodiversity. Many mitigation and adaptation strategies that could potentially improve air quality and thus help reduce emissions are currently available. These include shifting to renewable energy alternatives, increasing green spaces, adopting strategies to reduce waste, and shifting to plant-based diets. However, these have not been adopted at the scale required to adequately reduce GHG emissions.

The lack of development of, investment in, and implementation of existing technologies/policies is due to the lack of political will; in turn, this is attributable to limited public support due to perceived uncertainties about climate change impacts and a lack of immediate benefit to those asked to undertake mitigation actions. As a greater emphasis on non-climate-related benefits can motivate greater support for climate-mitigation actions (7), there is a critical need to evaluate the effectiveness and co-health benefits of available and future interventions to identify those that offer the greatest societal benefits.

To date, few studies have evaluated the efficacy of existing climate mitigation strategies beyond air quality regulations in some parts of the world. Given the complex interactome of direct and indirect impacts of climate change on health, individual climate mitigation interventions/policies will need to be widely implementable, scalable, and effective in practice. Consideration of how local conditions may be affected and the impact of local/global economic impacts will be critical.

Policies that yield synergistic benefits across sectors are needed. For example, the adoption of a plant-based diet would have multiple intersectional benefits, including reductions in the amounts of land and water used for animal food production, GHG pollution (methane), and ammonia volatilization—not to mention the direct health benefits. Meanwhile, achieving sustainable food production and a healthier diet could bring environmental, economic, and health co-benefits that outweigh the costs of climate mitigation measures. However, these measures will need to be evaluated in specific localities as shifts to plant-based diets in some low-resource countries may not be possible and may increase malnutrition. Likewise, community planning that encourages walking and cycling and the use of clean-energy public transportation systems will both reduce GHG emissions and improve overall health.

The public health and healthcare sectors' role in prevention of climate change health effects

Although the public health and healthcare sectors do not directly control government regulations or technology development, they will play an important role in the prevention and management of climate change-induced health risks through i) identification and communication of the health risks posed by climate change, ii) assessment of the co-health benefits of climate change mitigation strategies, iii) implementation of effective preventive measures, and iv) climate-proofing healthcare delivery.

As the climate crisis unfolds, the extent and severity of the health risks will depend upon the ability of public health and safety systems to respond to these challenges. Management of climate-related health risks will require intersectoral planning and coordination. Local public health departments will also need to be equipped to mobilize resources and issue warnings regarding severe weather/heat events to reduce their health impact. Healthcare delivery practices will need to adapt to adequately care for patients experiencing health-related consequences of climate change and to climate-proof the healthcare infrastructure itself. This will be particularly important in low-resource areas.

At the same time, healthcare systems will need to reduce their carbon footprint. In the United States alone, healthcare delivery is estimated to contribute 8.5% of all GHGs owing to the reliance on fossil fuels to run healthcare facilities and transport supplies, use of petrochemical-containing plastics, use of anesthetic gases in operating rooms, and the incineration of medical waste. The development of resilient healthcare systems globally will require methods for tracking their carbon footprint and interventions to decarbonize services and supply chains. Adoption of practices that reduce the carbon footprint of healthcare delivery could reduce the overall cost of healthcare, benefit the economy, and save lives.

Ensuring equitable climate-mitigation and adaptation strategies

It is widely acknowledged that poor and minority communities around the world, who generally bear little responsibility for driving climate change, will be most impacted by the associated health threats. Some climate adaptation strategies and policies may disproportionally benefit different groups, further exacerbating the vulnerability of disadvantaged individuals globally. Moreover, the implementation of some climate adaptation strategies may also amplify existing health disparities borne by these populations. For example, certain fossil fuel-reducing strategies (such as solar energy and electric vehicles) may only be available in affluent communities/countries and may therefore promote greater inequity. Building dams to manage floods in wealthy neighborhoods may exacerbate floods in areas with lower property values. Thus, it is imperative that all climate mitigation and adaptation strategies are designed to be deployed in an equitable manner to ensure the health and welfare of disadvantaged populations.

In conclusion, the scale of the impact of the climate crisis on human health and survival demands that we unite immediately to implement effective, equitable, and implementable strategies to protect the health of our planet and the people dependent upon it.

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