

Heatwaves and wildfires suffocate our healthy start to life: time to assess impact and take action

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Adverse environmental exposures in utero and early childhood are known to programme long-term health. Climate change, by contributing to severe heatwaves, wildfires, and other natural disasters, is plausibly associated with adverse pregnancy outcomes and an increase in the future burden of chronic diseases in both mothers and their babies. In this Personal View, we highlight the limitations of existing evidence, specifically on the effects of severe heatwave and wildfire events, and compounding syndemic events such as the COVID-19 pandemic, on the short-term and long-term physical and mental health of pregnant women and their babies, taking into account the interactions with individual and community vulnerabilities. We highlight a need for an international, interdisciplinary collaborative effort to systematically study the effects of severe climate-related environmental crises on maternal and child health. This will enable informed changes to public health policy and clinical practice necessary to safeguard the health and wellbeing of current and future generations.

Introduction

Pregnancy is a critical window of development that is particularly sensitive to environmental exposures. Such exposures put normal fetal development at risk and can have lifelong adverse impacts on the health of the offspring and potentially future generations; a concept known as the Developmental Origins of Health and Disease.¹ Air pollution has been identified as an environmental exposure that is associated with detrimental health effects on pregnancy and early life.² Prenatal exposure to ambient air pollution or cigarette smoke has been associated with adverse birth outcomes, such as preterm birth,^{3,4} low birthweight,⁴ intrauterine growth restriction (IUGR),⁵ and increased risk of sudden infant death syndrome.⁶

Our changing climate, including rising global temperature, is amplifying the frequency and severity of extreme environmental events such as heatwaves and wildfires.^{7,8} Accumulating evidence suggests that heatwaves are also associated with impaired pregnancy and birth outcomes, including preterm birth, low birthweight, and stillbirth.^{9,10} Much like the impact of ambient air pollution (emitted by industries, households, or vehicles), or cigarette (tobacco) smoke, exposure to smoke from bushfires (wildfires; emitted upon burning of a variety of trees and bushland) has been linked with impaired pregnancy and birth outcomes. The effects of wildfire smoke exposure effects on pregnancy and birth outcomes include abnormal birthweight, increased rates of prematurity, increased incidence of gestational diabetes, and hypertensive disorders of pregnancy.¹¹ Women from low-income and middle-income countries are already at higher risk of adverse pregnancy outcomes than women from high-income countries. A 2022 UN Environment Programme (UNEP) and GRID-Arendal report suggests that wildfires have a disproportionate impact on the world's poorest nations, including on women and girls, reflecting the scarcity of resources to rebuild after a wildfire crisis.¹²

Collecting and synthesising evidence on the effects of heatwaves and wildfire smoke exposures on pregnancy and birth outcomes is challenged by the heterogeneity of these perturbations. This heterogeneity includes the types of fires and what fuels them, definitions of extreme heat in terms of duration and intensity, and cumulative gestational days and trimester of exposure. Evidence generation is limited by reliance on administrative health data and failures to capture variations in individual heat and smoke exposure within cohorts. Hence, there is a paucity of robust data on long-term physical and mental health of pregnant women and their babies, underlying mechanisms of harm, effects on vulnerable and marginalised populations, and impacts on health-care services. Collectively, these observations suggest an urgent need for well designed longitudinal studies investigating the effects of heatwaves and wildfires on maternal and child health.^{10,11,13,14}

The rising burden

The Intergovernmental Panel on Climate Change Assessment Report 2021 concludes that we will see an increase in frequency of extreme environmental events around the globe, including droughts, heatwaves, and bushfires.¹⁵ This trend has already been realised as lived experience during the Australian summer of 2019–20 when severe drought and heat led to bushfires of unprecedented duration, severity and scale.¹⁶ These bushfires had substantial economic effect; insured economic losses were AUD\$2·21 billion within 5 months,¹⁷ and other losses have been estimated at \$100 billion.¹⁸ In January 2020, the Australian Capital Territory reported the worst air quality in the world (Air Quality Index readings ranging from 3400 to 7700; >200 is considered hazardous).¹⁹ The severity of maternal smoke exposure during the 2019–20 Australian bushfires was much higher than typical with the average concentration of particulate matter with an aerodynamic diameter of less than 2·5 µm (PM_{2.5}) being approximately 111·2 µg/m³ from Dec 7, 2019, to Jan 31, 2020,²⁰ compared

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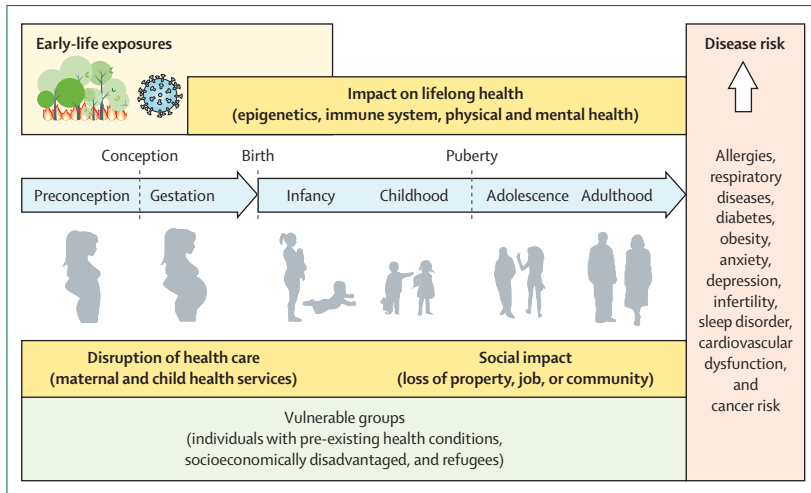


Figure: Impact of early-life exposure to heatwaves, wildfires, and COVID-19 on long-term health

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with approximately $6.4 \mu\text{g}/\text{m}^3$ over the same period in 2018–19. This represents an increase of approximately $104.8 \mu\text{g}/\text{m}^3$ attributable to bushfire smoke, which is much greater than that attributable to smoke reported in previous wildfire studies (approximately $3.0 \mu\text{g}/\text{m}^3$ in Colorado, USA in worst months;²¹ approximately $34\text{--}57 \mu\text{g}/\text{m}^3$ in Amazon fire season).²² A mirror-image wildfire event occurred through western USA through their 2020 summer and autumn seasons.⁸ The most extensively burnt areas from 2001 to 2016 were assessed to be the tropical belts of Africa, South and Central America and Australia.²³ Within this time series, southeast Asia (Myanmar, Laos, Thailand, and Vietnam), southern and far-east Russia, northern Kazakhstan, southern Europe, USA, and Canada were also substantially affected.²³ Given the changing climate, similar events are likely to become more frequent and intense around the world, with the UNEP and GRID-Arendal report projecting global increases in catastrophic wildfire events from the reference time of 2010–20, by factors of 1.08–1.14 by 2020–30, 1.20–1.33 by 2040–50, and 1.31–1.57 by 2090–2100.¹² Therefore, to mitigate the short-term and long-term risks to human health, it is crucially important to assess the impact of such events to foster preparedness for future events.

In the following sections, we elaborate on the knowledge gaps, specifically in relation to the potential effect of heatwaves and wildfires on maternal and child health and its mechanisms of action to highlight the disproportionate impact on vulnerable and marginalised groups and the importance of continuity of care. As the effects of climate change are compounded by the COVID-19 pandemic, we also discuss the unique synergistic effects of both perturbations on maternal and child health (figure). Finally, we emphasise the value of and need for multidisciplinary collaborative studies to understand the long-lasting socioeconomic and health impacts of extreme environmental events on current and future generations.

Impact on physical health

Heatwaves^{24,25} and wildfires^{26,27} increase fatalities and hospital admissions due to cardiovascular and respiratory health conditions around the world. These outcomes might be due to direct effects of exposure to wildfire smoke on cardio-respiratory health, psychological stress, and use of alcohol and drugs. Such events also cause alterations in lifestyle factors, including physical activity, sleeping patterns, and diet, which are particularly important through pregnancy. For instance, heatwaves and wildfires exacerbate sedentary lifestyle as people stay indoors and avoid outdoor physical activity due to concerns about the effects of extreme heat and smoke inhalation,²⁸ or because public health advice recommends staying indoors and reducing strenuous outdoor exercise.¹⁶ Children’s physical activity levels in particular have been shown to be affected when air quality is hazardous,^{29,30} or on extremely hot days.³¹ The physical activity and physiological health of women before conception and during pregnancy are crucially important for the optimal growth and development of offspring.^{32,33}

Moreover, postpartum, maternal health influences lactation,^{34,35} with consequent impacts on the developing child.³⁶ One study reported that breastfeeding practice was adversely affected during and after the 2016 Fort McMurray wildfire evacuations,³⁷ and a further study found contamination of breastmilk following the 2019–20 Australian wildfires.³⁸ Infants are reliant on their care providers for nutrition after birth, and it is crucial to provide appropriate infant feeding during natural disasters.³⁹ However, little is known about the influence of extreme heat and wildfires on the physiological health of women themselves before and during pregnancy, after delivery, and throughout the breastfeeding period.

Since women’s ability to thermoregulate is altered during pregnancy, it is vital to understand how extreme heat prevalent during heatwaves and wildfires impacts maternal health and the health of the offspring. A 2021 systematic review highlighted the increased burden of long-term metabolic health impairments following natural disasters such as floods, tsunamis, earthquakes, hurricanes, and ice storms.⁴⁰ However, the long-term effect on metabolic health of pregnant women and their babies following heatwaves and wildfires remains unknown.

Impact on neurodevelopment and mental health

Natural disasters lead to fear, uncertainty, separation from family and friends, loss of life and property, family and community disruption, and loss of livelihood. These emotions and experiences significantly increase post-traumatic stress, anxiety, and depression symptoms, and impair wellbeing.⁴¹ These effects might be compounded by pregnancy, which in itself is a period of increased psychological vulnerability.⁴¹ With respect to maternal and child health, prenatal maternal stress following natural disasters like floods and ice storms

has been linked with neurodevelopmental,^{42,43} and physiological impairment in children.^{44,45} Prenatal maternal stress and maternal psychological ill-health are also known to negatively impact on maternal–infant attachment, as well as breastfeeding and its associated benefits for both the mother and child.^{46,47} Despite the known association of other natural disasters with maternal and child mental health,⁴¹ the effect of heatwaves and wildfires on these outcomes has not been adequately investigated. Our lack of knowledge about maternal and family stress and the neurodevelopment of children following major heatwaves and wildfires and its associated factors (smoke exposure, disruption of family, community and health support, and social disadvantage due to property loss), limits our capacity to develop evidence-based strategies to mitigate these risks and provide the best support when they occur.

Mechanisms of action

The mechanisms by which heatwaves and wildfires affect the health of pregnant women and babies are poorly understood. Here we discuss potential mechanisms of action of exposure to extreme heat, or wildfires (smoke exposure or other injury during wildfires) on maternal and child health.

Through increased metabolism and associated heat production, without significant increase in body surface area, pregnant women are more prone to heat stress, with potential effects on hormonal responses and blood flow patterns with unknown effects on the developing fetus.¹⁰ Rises in temperature might also affect the maternal and fetal hormonal-metabolic milieu, including via altered lipoprotein metabolism, as has been shown to occur under excess heat conditions outside of pregnancy.⁴⁸ Heat has also been associated with profound effects on the diversity of gut microbiomes across animal species,⁴⁹ but this association has not been investigated in the mother–child context. As perturbed maternal microbiome impairs the offspring's immune system development and function,⁵⁰ which in turn might programme long-term cardiovascular and metabolic disease risk, it is crucial to investigate the impact of extreme weather events like heatwaves on the maternal and child microbiome and immune system.

Atmospheric particulate matter (PM_{2.5}) and associated toxic chemicals in wildfire smoke can penetrate deep into the respiratory system and the bloodstream (smaller particles can translocate into blood), potentially causing oxidative stress and inflammation which might impact the health of the pregnant woman, fetus, and exposed neonate.⁵¹ Recent evidence shows that following inhalation of smoke under real-life conditions, carbonaceous particles can translocate to the placenta.⁵² These particles were observed on both maternal and fetal sides of the placenta, suggesting that carbon particles can cross the placenta and might interfere with fetal development directly or alter epigenetic programming during the first 2000 days of life.⁵³

Maternal stress itself, as observed following natural disasters like wildfires, can alter metabolic programming of the offspring with long-lasting impact in terms of increasing susceptibility to metabolic disorders like diabetes, obesity, and hypertension.⁵⁴

However, how a severe heatwave and wildfire season influences these biological mechanisms and impacts the long-term health of the exposed pregnant woman and child remains poorly understood.

Synergistic impact of COVID-19 on maternal and child health

As the COVID-19 pandemic unfolded across the globe, certain regions experienced the consequences of the wildfires and the developing syndemic in close succession.⁵⁵ For example, eastern Australia (bushfires, followed by COVID-19) and western USA (COVID-19, followed by wildfires) are regions where back-to-back crises left little time for recovery. This is particularly concerning when we consider the compounding effects of extreme heat and COVID-19 on health,⁵⁶ or of wildfires and COVID-19 on health.⁵⁷ Although the combination of two adverse exposures or second hits has been well investigated (eg, combination of poor diet and physical inactivity), how the effects of natural disasters and global health crises modulate one another and impact maternal and child health remains unclear. A combination of such events is likely to impose more severe harm on pregnant women and babies than a single event. It is even more imperative to reveal these effects as we increasingly recognise the disproportionate impacts of COVID-19 on women and babies worldwide, not only from infection with the virus, but also from disruptions to maternal and child health services.^{58,59} Reduced access to care services is well known to result in increased adverse pregnancy outcomes including stillbirth.^{58,59} Restrictions on the number of health-care staff, family and friends allowed to support mothers at crucial times such as during childbirth, when a baby is in neonatal intensive care, or when a pregnancy loss has occurred will increase maternal stress.^{58,59} Similarly, loss of social cohesion through COVID-19 lockdowns in the postpartum period (eg, reduced visits of family and friends, reduced access to childcare and schooling for older children, job losses causing poverty and food insecurity, greater risk of domestic violence), a critical time for maternal–child bonding, could have long-term detrimental outcomes for both mothers and babies.^{58,59} It might therefore be expected that women who conceived during the extreme heat or wildfire season and gave birth during the pandemic would experience synergistic effects with potential debilitating consequences for short-term and long-term health of the newborns. This needs to be assessed urgently, so that effective preventive strategies can be implemented to support affected women and help every child achieve their full developmental potential.

	Evidence gaps	Research approaches required	Research team's requirements
Adverse pregnancy and birth outcomes: maternal outcomes (eg, miscarriage, hypertensive disorders, gestational diabetes, cardiorespiratory disorders, and mental health); fetal and neonatal outcomes (eg, congenital malformations, intrauterine growth restriction, preterm birth, stillbirth, and neonatal death)	<p>What types and levels of exposures (heatwaves, smoke, or maternal stress) are harmful to the outcomes of pregnancy? Which stages of the reproductive cycle are most vulnerable? What are the interactions of exposures with risk factors, social disadvantage, and comorbidities? What are the effects on Indigenous and ethnically diverse mothers and babies? What are the effects on women and babies of displaced populations (geopolitical and natural disaster refugees)? What is the interaction with the effects of concurrent or close in time additional crises (eg, COVID-19 pandemic, drought, and floods)</p>	<p>Quantitative studies to obtain individual mother and baby data on:</p> <ul style="list-style-type: none"> • Socio-demographics including family and social network support structures • Baseline maternal physical and mental health status • Environmental exposures (eg, through meteorological and air quality data), including timing and if mitigation strategies were used • Assessment of individual smoke exposure levels in biological samples (eg, urine, placenta, and serum) • Access to and models of health-care provision • Maternal, fetal, and neonatal outcomes with corroboration with clinical health records <p>Population-level administrative data</p> <ul style="list-style-type: none"> • Overlay of individual mother and child health and demographic data with population-level data <p>Meta-analyses of similar datasets</p> <p>Qualitative studies for more detailed assessment of individual pregnant women and new mothers' personal experiences of heatwaves and wildfires, including vulnerable or marginalised groups who might be less able to provide information through quantitative surveys</p>	<p>Epidemiologists, environmental scientists, geospatial scientists, perinatal biologists, clinical researchers in maternal child health care (eg, midwifery, obstetrics, fetal and maternal medicine, and neonatology), psychologists, social scientists, biostatisticians, and big data scientists</p> <p>Community advisers and scientific advisers</p> <p>National and international networks to harmonise study protocols and methodologies</p>
Mechanisms underlying adverse maternal and child health outcomes	<p>What are the mechanisms underlying adverse effects of heatwaves and wildfires on maternal and child health? What are the maternal, fetal and neonatal mechanisms of harm through heat stress, wildfire smoke exposure, or disaster-associated stress?</p>	<p>Detailed individual mother and child phenotypic data, as described above, and environmental exposure data, matched with prospectively collected maternal and child biometric measurements and biomedical sample collection; in particular:</p> <ul style="list-style-type: none"> • Maternal—hormonal, metabolic, and oxidative stress, immune function, and microbiome biomarkers • Fetal—biometric data including growth and placental blood flow • Neonatal—anthropometry, cord blood (hormonal, metabolic, oxidative stress, and immune profile), and microbiome biomarkers • Placental—macroscopic, microscopic, and molecular assessments • Genetics, epigenetics, and telomere length assessment 	<p>Multidisciplinary team comprising of researchers mentioned above, along with biomedical scientists and perinatal pathologists</p>

(Table continues on next page)

Support needs of vulnerable and priority groups

During natural disasters women are disproportionately impacted,⁶⁰ with more severe consequences for women in resource-poor settings, including women who live in remote and rural areas with less access to health services and infrastructure.⁶¹ Indigenous people occupy and care for around 25% of the world's land surface,⁶² and Indigenous women, who are often responsible for finding water, wood and food, frequently suffer the worst impacts of food insecurity, particularly if they are pregnant.⁶³ In post-colonial societies, evacuations from fire-affected communities can be disproportionately stressful for Indigenous women.⁶⁴ Refugees are also under-represented in the data, despite the disproportionate impact of natural disasters on transitioning communities who have experienced forced displacement.⁶⁵ Extreme weather events drive domestic and international migration flows, with more unplanned migration observed due to loss of property or employment following natural disasters.⁶⁶

However, little is known about the effects on migrating pregnant women and children. It is expected that severe environmental events such as heatwaves and wildfires will cause greater harm in mother-child pairs in these vulnerable and marginalised groups (Indigenous people, rural habitants, those from low-income countries or countries of war, ethnic minorities, and forced migrants). Therefore, a particular focus should be given to these communities when designing response and recovery strategies.

Women with pre-existing medical conditions (eg, diabetes, hypertension, and asthma), or mental health conditions (eg, anxiety and depression) should be a research and response priority as they are likely to be more adversely affected, as exposure to heatwaves and wildfires can modify or worsen these health conditions.^{21,24,26} Sexually and gender diverse groups are also marginalised during natural disasters,⁶⁷ such that sexually and gender diverse parent-child pairs might experience further

Evidence gaps	Research approaches required	Research team's requirements	
(Continued from previous page)			
Short-term (first 5 years after birth) physical, neurodevelopmental, and mental health outcomes	<p>What are the effects on maternal metabolic and cardio-respiratory health, sleep?</p> <p>What is the impact on maternal mental health, including substance use?</p> <p>What is the impact on mother-child bonding?</p> <p>What are the effects on family dynamics, social connectivity, and food and financial security?</p> <p>What are the effects on infant and young child's lifestyle, behaviours, and health-care use (eg, feeding, food choices, screen-time, exercise, health-care visits, and vaccinations)?</p> <p>What are the effects on child physical health (eg, allergy, asthma, growth, metabolic health, and hospital admissions)?</p> <p>What are the effects on child neurodevelopment?</p> <p>What is the impact on child's mental health?</p>	<p>Establishment of longitudinal mother and child birth cohorts in which detailed individual data on heatwave and wildfire exposures, baseline maternal and paternal characteristics, and pregnancy outcome data are available</p> <p>Maternal lifestyle, physical and mental health, and wellbeing assessments</p> <p>Periodic child assessments including child anthropometry, respiratory health, metabolic, and neurodevelopmental and mental health assessments</p> <p>Validated tools for all assessments</p>	<p>As above, with addition of clinical and biomedical researchers in adult health, paediatrics, and child neurodevelopment</p>
Long-term physical and mental health outcomes (life-course approach)	<p>What are the effects on maternal long-term physical health (including chronic cardiometabolic diseases, cancer) and mental health (substance use, anxiety, depression)?</p> <p>What are the effects on long-term physical and mental health of the offspring (eg, allergies, obesity, diabetes, cardiorespiratory diseases, substance use, anxiety, depression, and major psychiatric conditions)?</p> <p>What is the impact on general wellbeing of mothers and offspring including family and social connectiveness and financial security?</p>	<p>Longer-term follow-up of established mother and childbirth cohorts in which lifestyle, physical health, mental health, and general wellbeing are periodically assessed</p>	<p>As above, but with more involvement of adult health multidisciplinary teams comprising of clinician researchers, biomedical scientists, social scientists, epidemiologists, and biostatisticians</p>
Multidisciplinary collaborative research protocols, ethics approvals, and identified funding sources ought to be in place before extreme environmental events to avoid losing opportunities for prospectively collecting research data.			
Table: Approaches to closing evidence gaps on effects of heatwave and wildfire exposure on maternal and child health			

compounding effects. The incidence of domestic violence often increases in the wake of natural disasters, with severe consequences for women and children.⁶⁸

Importance of continuity of care

Climate disasters including bushfires and wildfires increase hospital admissions and overall burden on limited health-care resources.²⁷ Common to wildfires is an increased risk of premature and IUGR births.^{21,22,69} Premature and IUGR babies often require specialised care and support in a neonatal intensive care unit.⁷⁰ Services of the neonatal intensive care can be disrupted during natural disasters as was seen in the USA after Hurricane Katrina, compromising the provision of health care to the youngest and sickest babies, additionally aggravating stress levels of the mothers and families of the newborns.⁷⁰ Access to pregnancy care and maternal and child health follow-up services can also be disrupted during natural disasters as was seen in the aftermath of Hurricane Michael, in Florida, USA.⁷¹ Continuity of care to pregnant women is known to be beneficial for both the pregnant woman and offspring.⁷² The importance of continuity of care to pregnant women during natural disasters has been highlighted by the Queensland Flood 2011 study, which illustrated that continuity of care not only protects the women against adverse pregnancy outcomes, but also has positive effects on children's future neurodevelopment.⁷³ We hypothesise that vulnerable and marginalised groups who are already

disproportionately affected during natural disasters (as discussed here), might also be severely impacted by disruption of continuity of care; however, this remains poorly studied.⁷⁴ The need and provision of telehealth increases during natural disasters,⁷⁵ and it might be a feasible avenue to explore for providing continuity of care during such events. As we continue to develop strategies to prepare for and cope with future extreme environmental events, similar to the 2019–20 Australian wildfires but irrespective of where in the world, it is important to document their impact on access to family planning and maternal and child health services and to investigate how breakdown in continuity of care affects pregnant women and children, while also testing and implementing more resilient and culturally sensitive models of continuity of care in affected regions.

Towards an effective public health response

A healthy start to life from preconception through pregnancy and into the early neonatal period is crucial for achieving optimal physical and mental health, as well as social wellbeing, in the long-term for mothers and babies. In order to provide every child a healthy start to life, it is essential that our research, response, and recovery efforts during times of crises are directed towards supporting women, children, and young families. The 2020 WHO–UNICEF–*Lancet* Commission has also highlighted that to prevent the current and

future generations from debilitating consequences of climate change, there is a pressing need to prioritise and invest in the health of our children.⁷⁶ This effort will have profound health and economic benefits globally, and must be placed at the centre of our Sustainable Development Goals.⁷⁶ To learn from the current crises and be better prepared for future ones, we recommend the establishment of multidisciplinary collaborative studies aimed at collecting and analysing detailed information on how pregnant women, newborns, and young families experience heatwaves, wildfires, and associated crises, and how physical and psychological biological responses to exposures, access to health-care services, and social connectivity impact on their health in the short and long term (table). We need to learn from prospective quantitative,⁷⁷ mechanistic, and qualitative^{78,79} research to better grasp the magnitude and nature of the effects experienced during these traumatic events and develop a deeper understanding of how they might impact health trajectories (table). Equally critical is the involvement of consumers and community members and organisations, as well as engaging with health-care services, industry, media, and policy partners, to support effective strategies that shall emerge from these research and response efforts. Such holistic studies will help uncover direct and indirect effects of natural disasters like heatwaves and wildfires and compounding effects of syndemic events like COVID-19, and inform the development of public health interventions.

Conclusion

Recent environmental crises around the world including bushfires (wildfires) and record-breaking high temperatures, along with the COVID-19 pandemic, are an impetus to assess the synergistic impact of these environmental and health crises on the growth, development, and long-term health of our youngest generation. Particular attention needs to be focused on less well resourced regions of the world in which women and children are at greatest risk. These efforts will inform public health and clinical practice to design strategies to prevent short-term and long-term health impairments. To develop policies that will prove most effective at mitigating harms and promoting benefits, we must harness our ability across sectors to conduct collaborative quantitative and qualitative studies to strengthen our capacity to holistically assess the environmental and climate impact on health and wellbeing, and the effectiveness of preventive measures. Furthermore, it is crucial that prevention and recovery response strategies are developed with gender-equitable policies that empower the voices of women, particularly within socially disadvantaged communities. Such a joint effort will enhance preparedness for future events and provide the evidence to inform public health and clinical practice and shape policy to safeguard the health and wellbeing of our current and future generations.

Contributors

AB drafted the manuscript, figure, and table, and with CJN edited subsequent versions. NC contributed to revisions and generating graphics. DLD, MJP, AW, BKC, HC, MB, DAJMS, JED, CBP, SV, and RN contributed to revisions. All authors approved the final version.

Declaration of interests

We declare no competing interests.

Data sharing

Data will be shared on request to the corresponding author.

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