Appendices: Environmental threats to child brain development

Appendix I: Environmental threats

I. Chemical Exposures

Heavy Metals & Metalloids

- Lead (paint, dust, drinking water, soil, food, consumer products, occupational exposure including maternal and take-home exposure)
- Mercury (food, dental amalgams, consumer products)
- Arsenic (drinking water, soil, food, pressure-treated wood)
- Manganese (drinking water, industrial emissions, food)
- Cadmium (food, batteries, consumer products)
- Hexavalent chromium (drinking water, industrial emissions, soil, occupational exposure)

Pesticides & Agricultural Chemicals

- Organophosphates (food, drinking water, residential use, occupational exposure, drift from agricultural spraying)
- Organochlorines, including legacy compounds like DDT (food, breastmilk, soil)
- Neonicotinoids (food, drinking water)
- Pyrethroids (residential pest control, food, pet treatments, treated clothing/mosquito nets)
- Carbamates (food, residential pest control)
- Herbicides, including glyphosate, atrazine, 2,4-D (food, drinking water, residential lawn/garden use, drift from agricultural spraying)
- Fungicides, including mancozeb, chlorothalonil, strobilurins (food, residential use, occupational exposure)

Air Pollution

- Particulate matter, including PM2.5, PM10, ultrafine particles, and black carbon (traffic emissions, diesel exhaust, wildfires, cooking/heating, industrial sources, tobacco/vaping)
- Polycyclic aromatic hydrocarbons (PAHs) (traffic emissions, diesel exhaust, tobacco smoke, wood burning, grilled/charred foods, industrial sources)
- Volatile organic compounds (VOCs), including benzene and formaldehyde (traffic emissions, building materials, paints, cleaning products, gas stoves, tobacco/vaping, personal care products)
- Carbon monoxide (vehicle exhaust, gas stoves/heating, tobacco smoke, wildfires)
- Nitrogen oxides, including nitrogen dioxide (traffic emissions, gas stoves/heating, power plants, wildfires)
- Sulfur dioxide (coal-fired power plants, industrial facilities, diesel engines)
- Ground-level ozone (formed from reactions of nitrogen oxides and VOCs in sunlight)

Industrial Chemicals

- Flame retardants, including polybrominated diphenyl ethers (PBDEs), organophosphate FRs (furniture, electronics, building insulation, carpet padding, vehicle interiors, dust)
- Polychlorinated biphenyls (PCBs) (contaminated fish, breast milk, soil, old electrical equipment, building materials)
- Per- and polyfluoroalkyl substances (PFAS/"forever chemicals") (drinking water, food packaging, non-stick cookware, stain-resistant textiles, firefighting foam-contaminated sites, personal care products)
- Bisphenol A (BPA) and related bisphenols (canned goods, thermal receipt paper, food packaging, plastic containers, dental sealants)
- Phthalates (personal care products, vinyl flooring, food packaging, toys, medical tubing, air fresheners)
- Solvents, including toluene, perchloroethylene, trichloroethylene (dry cleaning, paints, adhesives, cleaning products, contaminated groundwater, occupational exposure, art supplies, nail polish/removers)
- Microplastics and nanoplastics (drinking water, food, air, dust, seafood, salt, bottled beverages)
- Dioxins and furans (contaminated food, industrial emissions, waste incineration, breast milk)
- Polychlorinated naphthalenes (PCNs) (industrial sites, e-waste, legacy contamination)
- Styrene (food packaging, disposable cups/plates, building materials, vehicle emissions)
- Vinyl chloride (PVC products, drinking water, occupational exposure)

II. Biological Threats

Waterborne

- Cyanotoxins, including microcystins, cylindrospermopsin, anatoxin-a (harmful algal blooms, drinking water, recreational water)
- Bacterial pathogens (drinking water, recreational water, flooding events)
- Parasitic infections, including Toxoplasma gondii (drinking water, recreational water)
- Viral pathogens, including enteroviruses (contaminated water, recreational water, inadequate sanitation)

Foodborne

- Mycotoxins, including aflatoxins (contaminated grains, nuts, dried fruits, spices)
- Domoic acid (contaminated shellfish during harmful algal blooms)

Vector-borne

- Zika virus (mosquitoes, sexual transmission, maternal-fetal transmission)
- West Nile virus (mosquitoes)
- Malaria (mosquitoes)
- Japanese encephalitis virus (mosquitoes)
- Tick-borne encephalitis viruses (ticks)

Indoor Biological Hazards

- Mold (water-damaged buildings, poor ventilation, flooding)
- Endotoxins (household dust, damp environments)

III. Stressors

Noise Pollution

- Chronic traffic noise (proximity to major roads)
- Aircraft noise (proximity to airports)
- Railway noise (proximity to rail lines / train stations)
- Industrial noise (proximity to factories / construction sites)

Heat

- Extreme heat exposure (during pregnancy and early childhood, heatwaves, urban heat islands, inadequate cooling)

Light Pollution

- Disrupted circadian rhythms and sleep deprivation from artificial light at night (streetlights, electronic devices)

Lack of Green Space

- Inadequate areas for play and exercise (lack of parks/playgrounds/sports fields, lack of transportation, unsafe neighborhoods)
- Lack of vegetation / tree canopy (high-density development, concrete-dominant neighborhoods)
- Lack of access to natural landscapes (high-density development, concrete-dominant neighborhoods, lack of transportation)

Radiation

- Medical and workplace radiation exposure (occupational exposure, radiotherapy and imaging in treatment and diagnosis of conditions caused by environmental harms)
- Radioactive contamination (nuclear accidents, mining, drinking water, radioactive waste sites, nuclear weapons testing/use, transportation accidents)

Life Disruptions from Climate Change and Other Environmental Disasters

- Physical displacement (home loss and housing instability from wildfires and other natural disasters, forced migration from climate-change-driven drought, famine, and war)
- Loss of educational access (closed schools from disasters, extreme heat, and smoke, virtual school days, destroyed supplies and facilities)
- Loss of community tentpoles (closed community organizations, churches, recreational facilities, libraries)
- Parental/caregiver stress leading to compromised ability to provide high quality child care (disaster-related mental health problems, job loss, property destruction, financial strain, relocation pressures)
- Social network disruption (caregiver death or injury, loss of familiar teachers, loss of peer relationships, loss of extended family support, loss of neighbor connections)
- Economic Hardship (reduced family resources that support healthy child brain development as a result of job loss, property loss, and medical costs)
- Government Services Impact (reduced funding for resources that support healthy child brain development, including schools, nutritional and health initiatives, and housing support, overwhelmed emergency services, preventing adequate response to child accidents, illnesses, and violent crime with brain development

implications, strained child protective services, reduced capacity for mental health services)
- Mental Health Problems (PTSD, anxiety, and depression from direct wildfire exposure, loss, and displacement, distress and anxiety from fears about future climate impacts and existential risk)
- Chronic Stress and Toxic Stress Response (prolonged disaster recovery, ongoing housing instability, cumulative exposure to multiple stressors, persistent uncertainty)
- Disrupted Healthcare Access (interrupted prenatal care, delayed well-child visits, reduced access to early intervention services)

IV. Nutritional Deficiencies

- Protein-energy malnutrition (PEM) (climate change, environmental degradation, drought)
- Iodine deficiency (soil depletion, climate change, groundwater iodine depletion)
- Zinc deficiency (soil depletion, climate change, reduced dietary diversity from environmental degradation)
- Iron deficiency (soil depletion, heavy metal contamination reducing absorption, air pollution, helminth infections from poor sanitation)
- Vitamin A deficiency (soil depletion, reduced dietary diversity from environmental degradation)
- Omega-3 deficiency (overfishing, pollution, climate change affecting fish stocks, reduced dietary diversity from environmental degradation)
- Folate/B-vitamin deficiencies (soil depletion, reduced dietary diversity from environmental degradation)
- Calcium deficiency (soil depletion, pollution, reduced dairy production from environmental degradation)

Appendix II: How Wildfires Threaten Child Brain Health

- Air Pollution
    - Including particulate matter, polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), carbon monoxide, nitrogen oxides, sulfur dioxide, and ground-level ozone
    - Exposure both during active fire and in weeks and months after, due to ash resuspension and continued off-gassing
    - Impacts on indoor and outdoor air quality
- Water and Soil Pollution
    - Including heavy metals, industrial chemicals, and other toxic substances released during the burning of homes, businesses, factories, and other structures
    - Concentrated exposure from fire debris dump and recycling sites
    - Long-term community impacts
- Food Contamination

    - Produce contaminated by smoke, water, and soil exposure
    - Livestock affected by toxins
    - Long-term community impacts
- Firefighting Exposures
    - Toxic chemicals used in fire extinguishing agents
    - Acute prenatal exposure to extreme heat and toxic chemicals by pregnant firefighters, emergency responders, police officers, and others
    - Take-home contamination from firefighter family members
    - Mold in homes, schools, and other buildings from water damage caused by attempting to douse flames
- Heat Exposure
    - Maternal hyperthermia affecting brain development
    - Shut down electrical grid resulting in loss of air conditioning, with resulting sleep disruption
- Nutritional Deficiencies
    - Due to acute food shortages, loss of particular foods implicated in brain health, or soil depletion driven crop deficiencies
- Infectious Disease Changes
    - Altered patterns of vector-borne illnesses (mosquito and tick-borne diseases) that increase risk of neurological infections
- Fueling Climate Change
    - Climate change not only makes wildfires worse: wildfires make climate change worse. As a result, when we are thinking about the impact of wildfires on child brain health, we must account for the increased risks that stem from exacerbating climate change.
    - There are two main mechanisms through which wildfires affect climate change: first, they release large amounts of carbon dioxide, black carbon, and other greenhouse gases into the atmosphere; second, by destroying forests, they reduce the capacity for carbon absorption.
- Physical Displacement
    - Loss of home to wildfire
    - Housing instability
    - Migration to another city, state, or country
- Loss of Educational Access
    - School closings
    - Virtual school days
    - Destroyed supplies
    - Cancelled classes, enrichment, and after-school classes
    - Teacher turnover and staffing shortages
    - Disrupted school routines and instructional continuity
- Loss of Community Tentpoles
    - Closed community organizations, churches, rec leagues, and other entities
- Parental/Caregiver Stress
    - When parents face wildfire-related stresses and displacements that can impact their ability to provide quality care to their children

- Social Network Disruption
    - Disrupted or severed attachment relationships, including from primary caregiver death
    - Loss of familiar teachers
    - Loss of peer relationships, extended family support, and neighbor connections
- Economic Hardship
    - Reduced family resources that support healthy child brain development as a result of job loss, property loss, and medical costs
- Government Services Impact
    - Reduced local and state funding for resources that support healthy child brain development, including schools, nutritional and health initiatives, and housing support, as a result of major wildfire-related budgetary expenditures and reduced tax revenue going forward
    - Overwhelmed emergency services, preventing adequate response to child accidents, illnesses, and violent crime with brain development implications
    - Strained child protective services
    - Reduced capacity for mental health services
    - Mental Health Problems
    - Mental health impacts, including PTSD, anxiety, and depression from direct wildfire exposure, loss, and displacement
    - Climate-related distress and anxiety (youth fears about future climate impacts and existential risk)
- Chronic Stress and Toxic Stress Response
    - Prolonged activation of stress response systems affecting brain development
    - Cumulative impact of multiple simultaneous stressors
- Disrupted Healthcare Access
    - Interrupted prenatal care (with implications for neurodevelopment)
    - Delayed well-child visits, postponing the diagnosis and treatment of illnesses and conditions that affect brain development
    - Reduced access to early intervention services
- Loss of Access to Green Space
    - Reduced opportunities for outdoor play
    - Reduced opportunities for physical exercise
    - Reduced opportunities for independent exploration

Appendix III: California-Specific Resources and Initiatives

California's Policy and Regulatory Context:

Historical Overview

- California Legislative Analyst's Office: Frequently Asked Questions about Wildfires in California - Background on California's historical wildfire-related

activities, division of roles and responsibilities, and related funding for schools and local governments.

Climate Change Impacts on K-12 Education

- California Legislative Analyst's Office: Climate Change Impacts Across California - K-12 Education - Report outlining how changing climate is affecting early childhood and K-12 Education and key issues the Legislature faces in responding to those impacts.
- A Call to Action: Climate Resilient California Schools - Comprehensive policy framework for climate-resilient schools, including recommendations to strengthen school infrastructure, improve indoor air quality, enhance emergency preparedness, support educational continuity, and protect student health during climate-related disasters such as wildfires.

School Ventilation and Infrastructure Funding

- California Schools Healthy Air, Plumbing, and Efficiency (CalSHAPE) Program - A state initiative created in 2020 by Assembly Bill 841 and administered by the California Energy Commission, including a $190 million investment in HVAC assessments, ventilation upgrades, and energy efficiency improvements.
- Assembly Bill 2232 (2021–2022): School HVAC Systems - Includes policies regarding HVAC inspection and maintenance, ventilation improvements, and air filtration in school buildings.

School Health, Safety, and Emergency Response Policies

- California Department of Education Wildfire Recovery Frequently Asked Questions - This guidance outlines how California schools respond to wildfire events, including reopening procedures, air filtration, attendance accounting, displaced students, and emergency reimbursement.

Child and Family Well-Being

Wildfire Impact

- UC Berkeley Center for the Study of Child Care Employment Report: When the Playground Was Coated in Ash: The Impact of the January 2025 Wildfires on Los Angeles Child Care Programs
- Los Angeles Times: How the L.A. Fires Are Taking a Traumatic Toll on Kids

Resources

- Supporting Children and Youth During and After a Wildfire (CSU Chico) - Research-informed resources focused on the psychosocial impacts of wildfire,

including a playbook for schools and non-profit organizations and children's books that can be used to talk about natural disasters.

Appendix IV: Further reading

Environmental threats

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Chemical exposures

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Brain development

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How Does Air Quality Affect Early Childhood Development? (2025, May 20). *Center on the Developing Child at Harvard University*. https://developingchild.harvard.edu/resources/working-paper/air-quality-affects-early-childhood-development-and-health/

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How Water Affects Child Development | Working Paper. (2024, June 25). *Center on the Developing Child at Harvard University*. https://developingchild.harvard.edu/resources/working-paper/water-affects-child-development/

A Call to Action

Protecting children's environmental health

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Credits

Prepared by Dr. Adam Benforado (Drexel University), Dr. Silvia Bunge (University of California Berkeley), Dr. Carlos Cardenas-Iniguez (University of Southern California), Dr. Jennie Grammer (University of California Los Angeles), and Dr. Jaimie Steinmetz (Institute for Health Metrics and Evaluation), on behalf of the Child Brain Policy Initiative (directed by Dr. Emily Murphy (University of California College of the Law, San Francisco)). This work was supported by the California Bench to School Initiative at University of California College of the Law, San Francisco.