

The Impact of Climate Change on the Neurodevelopment of Children: A Scoping Review

Ibtissam El Ouakili ^{a,*}, Carolien Van brabant ^{a,*}, Dirk van West ^{a,b,c}

*These authors contributed equally to this work and share first authorship

^a University Centre of Child and Adolescent Psychiatry (UKJA), Ziekenhuis aan de Stroom (ZAS), Antwerp, Belgium

^b Faculty of Medicine and Health Sciences, Collaborative Antwerp Psychiatric Research Institute (CAPRI), University of Antwerp, Belgium

^c Faculty of Psychology and Educational Sciences, Vrije Universiteit Brussel, Brussels, Belgium

dirk.vanwest@zas.be

Keywords

Children ; climate change ; neurodevelopment

Abstract

Objective:

Climate change introduces environmental stressors that may affect the developing brain. Children are particularly vulnerable due to biological sensitivity and social exposure. This review summarizes evidence on climate-related impacts on neurodevelopment.

Methods:

A scoping review was conducted focusing on four major exposures: air pollution, extreme temperatures, natural disasters, and endocrine-disrupting chemicals (EDCs). Findings across cognitive, behavioral, and neurobiological outcomes were synthesized.

Results:

Air pollution is linked to structural brain alterations, disrupted functional connectivity, and higher risks of autism, ADHD, and cognitive delay. Extreme heat and cold are associated with poorer language and cognitive performance, sleep disturbances, and behavioral problems. Natural disasters influence development through prenatal stress, trauma, and unstable environments. Increased EDC exposure contributes to neuroinflammation, oxidative stress, and epigenetic changes. Socioeconomically disadvantaged children show the greatest vulnerability.

Conclusion:

Climate change presents a significant risk to child neurodevelopment through interacting environmental and psychological pathways.

Introduction

Climate change, as defined by the United Nations, refers to long-term alterations in global temperature and weather patterns. The World Health Organization (WHO) further emphasizes that climate change affects multiple determinants of human health, such as clean air, safe drinking water, adequate nutrition, and secure shelter, posing a severe threat to public health and potentially reversing decades of progress in global health outcomes. Climate change affects both natural and human systems, including the functioning of healthcare systems. Currently, 3.6 billion people live in regions with high vulnerability to climate change, and populations in these areas have experienced mortality rates from extreme weather events fifteen times higher than those in more resilient regions over the past decade. Health impacts arise through various pathways, including extreme weather events, food system disruption, and increases in zoonotic, food-, water-, and vector-borne diseases (1).

Beyond physical and environmental consequences, awareness of climate change can negatively influence the psychological well-being of children, with anxiety and worry being the most frequently

reported emotional responses. In addition to these psychological effects, climate change may also influence the neurodevelopment of children and adolescents. Neurodevelopment involves the formation and maturation of the brain beginning in the prenatal period, and environmental factors play a crucial role in shaping these processes. Disruptions during sensitive periods, such as those associated with synaptogenesis, may lead to lasting impairments. Due to their cognitive and physiological developmental stage, children and adolescents are particularly vulnerable to adverse consequences of climate change, including exposure to traumatic events, nutritional deficiencies, environmental toxins such as air pollution, and temperature extremes (2, 3).

The purpose of this review is to summarize current knowledge on how climate change affects neurodevelopment in children.

Methods

A scoping review methodology was adopted to address the research objectives of this study. This approach is appropriate given that the aim of this study is to summarize what is currently known about the impact of climate change on neurodevelopment and to highlight areas requiring further research. We followed the Arksey

and O'Malley framework, which consists of five stages: identifying the research question, conducting a systematic search, selecting relevant studies, charting the data, and synthesizing and reporting the results (4). The guiding research question for this review was: "What is known about the effects of climate change on neurodevelopment in children and adolescents?"

Inclusion and exclusion criteria

This review included studies involving (unborn) children and adolescents up to 18 years of age, in accordance with the WHO definition of a child. Qualitative, quantitative, and mixed-method studies were eligible. In studies that included both adults and children, only those reporting child-specific data were retained. No geographic restrictions were applied, since the aim was to provide a global overview of the available evidence. The search was limited to publications in English and Dutch, with no restrictions on publication date. Eligible studies examined the relationship between climate change and neurodevelopmental outcomes in children and adolescents, including environmental exposures such as air pollution, nutritional stressors, temperature changes, and climate-related traumatic events that may affect brain development or psychological functioning. No formal quality assessment was performed, as the primary aim of this scoping review was to map and summarize the available evidence.

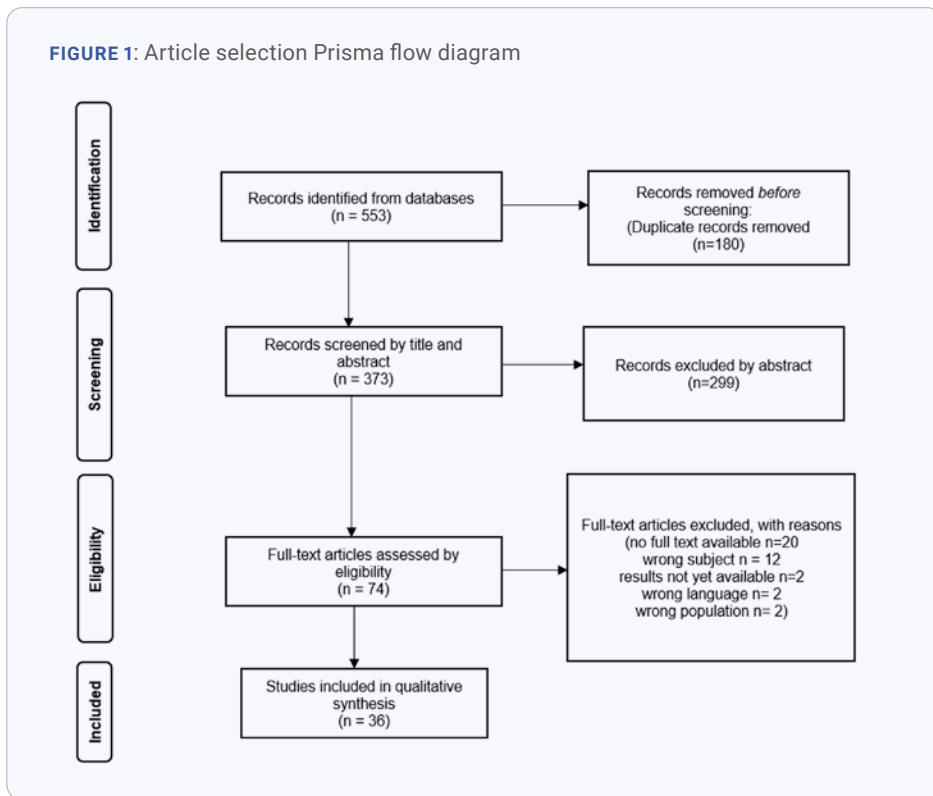
Search strategy

Searches were conducted in six academic databases (PubMed, Web of Science, GreenFILE, Cochrane Evidence-Based Medicine, Embase, and Scopus) in October 2025. The full search terms are presented in Table 1.

Study selection process

All identified records were imported into EndNote (version 2025). The references were then uploaded into the systematic review platform Rayyan, where duplicates were removed. Titles and abstracts were independently screened by two reviewers according to the predefined inclusion and exclusion criteria. Articles that met the eligibility criteria were subsequently assessed through full-text screening, and reasons for exclusion were documented. A third reviewer was not required, as any disagreements were resolved

FIGURE 1: Article selection Prisma flow diagram



through discussion. The screening process and study selection are illustrated in the PRISMA flow diagram (Fig. 1).

Data extraction

Data were manually extracted by one reviewer and verified by a second reviewer for accuracy. Extracted information included: author(s), year of publication, study location, study aim, population characteristics, sample size, methodology, and key findings (Table 2).

Synthesis

A narrative synthesis approach was used to summarize the findings across the included studies, drawing on textual descriptions to compare and integrate evidence.

Results

The studies included in this review demonstrate that climate change, through exposure to extreme heat, ambient air pollution (e.g., PM2.5, NO2), endocrine disruptive chemicals (EDCs) and natural disasters, can affect neurodevelopment in children.

TABLE 1: Search terms

Search number	Search terms
#1	('child*') OR ('adolescent*') OR ('teen*') OR ('youth') OR ('young people') OR ('school children') OR ('schoolchildren*') OR ('school age*') OR ('school-age*') OR ('infant*') OR ('newborn*') OR ('neonate*') OR ('toddler*') OR ('early childhood') OR ('young child')
#2	noft('neurodevelopment*') OR noft ('brain development') OR noft (cognitive development')
#3	Noft ('climate change') OR noft ('global warming') OR noft ('environmental change') OR noft ('climate crisis')

1. PM2.5 = particulate matter, particles ≤ 2.5 µm; NO2 = nitrogen dioxide

TABLE 2: Data extraction

Paper	Country	Research purpose/question	Research type and population (sample size)	Important findings
Odo DB, Yang JA, Dey S, Hammer MS, van Donkelaar A, Martin RV, et al. A cross-sectional analysis of long-term exposure to ambient air pollution and cognitive development in children aged 3–4 years living in 12 low- and middle-income countries. <i>Environ Pollut.</i> 2023;318.	Benin, Burundi, Cambodia, Chad, DRC, Honduras, Jordan, Rwanda, Senegal, Timor-Leste, Togo, Uganda	Is annual average exposure to PM2.5 associated with delays in indicators of cognitive development among children aged three to four years?	Cross-sectional study with children 3-4 years old living in low- and middle-income countries (n=57647).	Findings suggest that exposure to ambient PM2.5 is cross-sectionally associated with indicators of cognitive delay in young children living in LMICs. There was between-country variation in the effects of PM2.5 on cognitive delay.
Thompson R, Stewart G, Yu T, Jephcote C, Lim S, Barratt B, et al. Air pollution, traffic noise, mental health, and cognitive development: A multi-exposure longitudinal study of London adolescents in the SCAMP cohort. <i>Environ Int.</i> 2024;191.	United Kingdom	Is ground-level ozone exposure in relation to adolescent executive functioning?	Longitudinal cohort with adolescents from 39 different schools (n=7744).	Strong evidence indicates detrimental associations between ground-level ozone exposure and executive functioning during adolescence, alongside supportive evidence for associations between various other environmental exposures (like noise pollution) and psychological outcomes.
Barbalat G, Guilbert A, Adelaide L, Charles M-A, Hough I, Launay L, et al. Impact of early life exposure to heat and cold on linguistic development in two-year-old children: findings from the ELFE cohort study. <i>Environ Health Global Access Sci Sour.</i> 2025;24(1).	France	What is the effect of ambient temperature on linguistic development in children?	Cohort study with 2-year-old children (n=12163).	Exposure to night-time heat during the second trimester of pregnancy, as well as exposure to daytime and night-time heat during the first seven months postpartum, was associated with lower vocabulary production scores on the MB-CDI at two years of age.
Zhuo H, Warren JL, Bellia G, Wang P, Chen K, Liew Z, et al. High ambient temperature during pregnancy and offspring cerebral palsy: A population-based study in California. https://doi.org/10.1101/2025.05.21.253228071 .	United States	To examine whether prenatal exposure to high ambient temperatures is associated with an increased risk of cerebral palsy in offspring.	Case control study with children with cerebral palsy (n=5938) and control (n=1,092,313).	Prenatal exposure to higher ambient temperatures was associated with an increased risk of childhood cerebral palsy, particularly during early pregnancy (gestational weeks 0–3). These associations remained robust across sensitivity analyses and showed a positive trend with cumulative exposure throughout gestation.
Tromberg J. Fine particulate matter exposure and pediatric mental health outcomes: An integrative review. <i>J Nurs Scholarsh.</i> 2023;55(5):977–1007.	The studies were conducted in United States (5), England and Wales (4), China (3), Denmark (2), Taiwan (1), South-Korea (1), and Sweden (1)	Is exposure to fine particulate matter (PM2.5) potentially correlated with poor mental health outcomes among children and adolescents aged 18 or younger?	Integrated review: included studies covered both children and adolescents, with sample sizes ranging from 130 to over 1,4 million participants.	Evidence suggests a possible association between early-life exposure to fine particulate matter and the development of autism in children, particularly during the first three years of life/ Findings for ADHD were mixed.
Brumberg HL, Karr CJ. Ambient air pollution: Health hazards to children. <i>Pediatrics.</i> 2021;147(6).	United States	What are the health hazards of ambient air pollution for children?	Policy commentary and review of multiple studies; national-level data.	Summarizes multiple systematic reviews showing that prenatal and postnatal exposure to traffic-related air pollution (TRAP) and PM2.5 increases the risk of autism spectrum disorder (ASD), ADHD, and lower cognitive function. Identifies oxidative stress, inflammation, endocrine disruption, and epigenetic changes as biological pathways linking pollution to neural injury.
Payne-Sturges DC, Marty MA, Perera F, Miller MD, Swanson M, Ellickson K, et al. Healthy Air, Healthy Brains: Advancing Air Pollution Policy to Protect Children's Health. <i>Am J Public Health.</i> 2019;109(4):550–4	United States	Effect of combustion-related air pollution on neurodevelopment in children.	Policy commentary and review of diverse US cohorts: includes epidemiological and animal studies.	Combustion-related air pollutants (PM2.5, NO ₂ , PAHs) are linked to reduced IQ, developmental delays, ADHD, and structural brain changes. Climate change exacerbates exposure via wildfires and heat.
Nunhes ML, Cunha A-JLA. Neurodevelopment and climate change. <i>J Pediatr.</i> 2025;101: S34–S9.	Brazil	Impact of climate change on neurodevelopment and mental health in children and adolescents.	Narrative review based on recent literature and global data.	Climate change affects neurodevelopment through air pollution-induced neuronal loss, glial inflammation, and altered microbiota, linking these to ADHD, autism, and anxiety. Vulnerable groups (e.g. children, indigenous communities) are disproportionately affected. Early life exposure is critical.
Malaspina D, Howeel EA and Spicera J. Intergenerational Echoes of Climate Change. <i>JAMA Psychiat.</i> 2020;77(8):778–80.	United States	How do extreme temperatures during pregnancy affect neurodevelopment and psychiatric risk in offspring?	Narrative review of >40 studies.	Prenatal exposure to extreme heat or cold increases risk of adverse pregnancy outcomes and long-term psychiatric disorders. Effects are amplified in low-resource urban areas due to heat islands and lack of access to cooling. Climate change may perpetuate intergenerational health inequities.
Veras MM, Saldiva PHN. Impact of air pollution and climate change on maternal, fetal and postnatal health. <i>J Pediatr.</i> 2025;101: S48–S55.	Brazil	What are the effects of air pollution and climate change on gestation, fetal development and postnatal health?	Narrative review of 86 systematic reviews.	Neurodevelopment is negatively influenced by prenatal and early life exposure to air pollution. Changes in structural morphology and impairments on intellectual functioning, memory and learning, attention and executive functions, verbal language, numeric ability, and motor and/or sensorimotor functions are also affected.

<p>Perera F. Pollution from Fossil-Fuel Combustion is the Leading Environmental Threat to Global Pediatric Health and Equity: Solutions Exist. Int J Environ Res Public Health. 2017;15(1).</p>	<p>United States</p>	<p>Review the data on the health impacts of fossil fuel pollution, highlighting the neurodevelopmental impacts and describe available means to achieve a low-carbon economy.</p>	<p>Commentary review.</p>	<p>Emphasizes synergistic effects between air toxics and climate change, identifying epigenetic and neuroinflammatory mechanisms as pathways of damage to the developing brain.</p>
<p>Yu T, Zhou L, Xu J, Kan H, Chen R, Chen S, et al. Effects of prenatal exposures to air sulphur dioxide/nitrogen dioxide on toddler neurodevelopment and effect modification by ambient temperature. Ecotoxicol Environ Saf. 2022;230.</p>	<p>China</p>	<p>What are the effects of prenatal exposure to SO2 or NO2 on toddler neurodevelopment and the effect-modification by ambient temperature.</p>	<p>A prospective birth-cohort with a total of 184,546 parents or guardians of children.</p>	<p>Prenatal increased exposure to SO2 and NO2 from industrial, transportation, and building sources was strongly associated with higher odds of ADHD symptoms (ORs 1.79–5.71, p<0.001). This association was stronger in boys, children younger than 12 years of age, those exposed to passive smoking, and those who were non-breastfed.</p>
<p>Bonthrone AF B, Piyasena C, Counsell SJ. The Effects of Climate Change on Children's Health. Pediatr Clin North Am. 2025;72(5):991–1001.</p>	<p>United States</p>	<p>What are the neurodevelopmental and educational sequelae of climate change on children?</p>	<p>Narrative review of 84 articles.</p>	<p>Rising ozone and particulate matter levels (linked to climate change) worsen asthma and indirectly affect oxygen delivery to the brain, which can impair cognitive development. Children exposed to floods, wildfires, and heat experience higher rates of PTSD, anxiety, and depression. The importance of food security after birth is evidenced by studies documenting that malnutrition during infancy and childhood is associated with less favourable neurodevelopmental outcomes.</p>
<p>Butman JL, Bermannhia T, Huang JY, Huang P, Miller JG, Uy JP, et al. Exposure to Fine Particulate Matter During Pregnancy Is Associated with Hippocampal Development in Offspring. BP: GOS. 2025;5(4):100490.</p>	<p>Singapore</p>	<p>Does prenatal exposure to fine particulate matter (PM2.5) affect hippocampal volume development in children from early to middle childhood, and is this related to later emotional or behavioural problems?</p>	<p>Cohort study with 325 mother-child dyads.</p>	<p>Late gestational PM2.5 exposure (weeks 36–40) was associated with slower bilateral hippocampal volume growth from ages 4.5 to 10.5 years in 325 children (Singapore GUSTO cohort). Faster right-hemisphere hippocampal growth predicted more externalizing and attention problems at age 10, reflecting neurobehavioral dysregulation.</p>
<p>Kidd SA, Gong J, Massazza A, Bezgrebelina M, Zhang Y, Hajjat S. Climate change and its implications for developing brains - In utero to youth: A scoping review. J Clim Change Health. 2023;13.</p>	<p>Netherlands</p>	<p>What are the major considerations of the peer-reviewed literature that address climate change as it relates to brain development and health from early development through to youth populations?</p>	<p>Scoping review of 40 articles, with an upper age limit 24 years.</p>	<p>Changing climate patterns and weather extremes have substantial and wide-ranging effects on developing brains. These relationships occur within complex systems with both direct (e.g., hyperthermia, brain injury) and indirect (e.g., vector borne illness, malnutrition) effects, indexing as a function of the weather variables involved and geographic contexts alongside population, socioeconomic, and cultural characteristics. It is a consistent observation that individuals and populations lacking resources and experiencing inequities, as in other climate-health impact relationships, have the poorest outcomes.</p>
<p>Padmanabhan S, Tharan O. Impact of Climate Change on Neurodevelopmental Disorders in Pediatrics. J Res Appl Sci Biotechnol. 2024;3(1):368–82.</p>	<p>United States</p>	<p>What are the causal mechanisms by which climate change impacts neurodevelopmental disorders in children, what are the related health consequences, and what protective and policy strategies can mitigate these effects?</p>	<p>Narrative review with articles about children. No specific sample size is reported.</p>	<p>The review identifies several neurodevelopmental outcomes linked to climate-related environmental stressors: - ADHD and learning disabilities associated with air pollution (PM2.5, ozone). - Autism spectrum disorder (ASD) linked to exposure to heavy metals (mercury, lead) and phthalates. - Developmental delays related to pesticide exposure and heat stress. - Behavioural and emotional issues resulting from psychosocial stressors (displacement, food insecurity, family stress).</p>
<p>Yu Hg. Effects of extreme temperature on childhood cognitive development: evidence from China. Educ Econ. 2024.</p>	<p>China</p>	<p>What are the long-term effects of extreme temperature during infancy on school-aged children's cognitive development in China?</p>	<p>Quantitative, observational study using longitudinal survey data of 2894 children aged 10-16 years, born between 1995-2011, across 159 counties in China.</p>	<p>One additional low-temperature day during infancy lowers word test score by 0.2 points and math test score by 0.1 points. Boys are more affected by moderately cold days (-5-0°C), while girls are more affected by severely cold days (<-5°C). Children in southern China and those from unsupportive home environments are more vulnerable. Gender-specific mechanisms include physiological vulnerability in boys and gender-biased resource allocation disadvantaging girls.</p>
<p>Briker S, Tran KT, Visoki E, Gordon JH, Hoffman KW, Barzilay R. Association Between Extreme Heat and Externalizing Symptoms in Pre- and Early Adolescence: Findings from the ABCD Study. J Am Acad Child Adolesc Psychiatry. 2025;3(3):713–24.</p>	<p>United States</p>	<p>What are the associations between extreme heat and externalizing symptoms or suicidal behaviour among US preadolescents?</p>	<p>Longitudinal cohort (N= 8,120, mean age 9.89 years).</p>	<p>Each increase in days ≥90°F is significantly associated with higher externalizing symptom counts (aggression, impulsivity, hyperactivity) in U.S. children aged 9–12 (N=8,120). Importantly, the association remained significant when covarying for individual demographics and multiple geocoded neighbourhood characteristics.</p>

Paper	Country	Research purpose/question	Research type and population (sample size)	Important findings
Zundel CG, Ely S, Brokamp C, Strawn JR, Jovanovic T, Ryan P, et al. Particulate Matter Exposure and Default Mode Network Equilibrium During Early Adolescence. <i>Brain Connect.</i> 2024;14(6):307–18.	United States	What is the impact of particulate matter (PM2.5) on resting-state functional connectivity (rsFC) of the default mode network (DMN) and three key attention networks: dorsal attention, ventral attention, and cingulo-opercular?	Longitudinal cohort with 9–10-year-old children (n = 11,876) and caregivers.	PM2.5 exposure was associated with disrupted maturation of the default mode network (DMN) and attention networks, both crucial for cognitive and emotional regulation.
Webb D. Critical Periods in Cognitive and Socioemotional Development: Evidence from Weather Shocks in Indonesia. <i>Econ J.</i> 2024;134(660):1637–65.	Indonesia	What are the critical periods during childhood when weather shocks affect long-term cognitive and socioemotional development in rural Indonesia?	Quantitative, longitudinal observational study with >30,000 children born between 1988–2000.	There is a critical period the age of 2 where exposure to adverse weather conditions (drought or excess rainfall) leads to significant declines in adult cognitive ability. Poor early nutrition is linked to reduced dendritic growth and myelination, aligning with recognized neurobiological pathways of developmental impairment.
Assari S, Zare H. Extreme Heat Exposure Is Associated with Higher Socioeconomic Disadvantage and Elevated Youth Delinquency. <i>J Soc Mat Hum Eng Sci.</i> 2024;3(1):15–28.	United States	What are the association between extreme heat exposure and delinquency among children and what are the potential mediating roles of neighbourhood socioeconomic status?	Cross-sectional study with participants that were 9–10 years old at baseline. (n=11878).	Exposure to extreme heat is associated with increased individual delinquency among children. This can be attributed to several factors, including physiological stress responses to heat, which can impair cognitive functioning and self-regulation. Mental health may also worsen under heat extremes.
Parenteau AM, Hang S, Swartz JR, Wexler AS, Hostinar CE. Clearing the air: A systematic review of studies on air pollution and childhood brain outcomes to mobilize policy change. <i>Dev Cogn Neurosci.</i> 2024;69.	United Kingdom	Synthesize empirical evidence linking outdoor air pollution to brain outcomes in children.	Systematic review of 40 studies, which included measures of air pollution and brain outcomes at various points in development.	Air pollution exposure is associated with a range of structural brain alterations in children, including alterations in cortical thickness and surface area, white matter volume, and subcortical volume.
Assari S, Zare H. Extreme Heat Exposure and Adolescent Cognitive Function. <i>Open J Neurosci.</i> 2025;3(1).	United States	What is the association between extreme heat exposure and cognitive outcomes among 9–10-year-old children?	Cross-sectional study with participants that were 9–10 years old at baseline. (n=11878).	Children exposed to extreme heat had slightly lower cognitive function scores, even after adjusting for other factors.
Assari S, Zare H. Extreme Heat Exposure is Associated with Lower Learning, General Cognitive Ability, and Memory among US Children. <i>Open J Neurosci.</i> 2025;3(1):10–22.	United States	What is the relationship between extreme heat exposure and various domains of cognitive function in children.	Cross-sectional study with participants that were 9–10 years old at baseline. (n=11878).	Extreme heat exposure is significantly associated with lower learning, memory, and general cognitive ability in U.S. children (ages 9–10).
Assari S, Najand B, Zare H. Heat Exposure Predicts Earlier Childhood Pubertal Initiation, Behavioral Problems, and Tobacco Use. <i>Glob J Epidemiol Inf Dis.</i> 2025;5(1).	United States	Does exposure to extreme heat predict earlier pubertal onset in children, and is early puberty associated with behavioural problems and tobacco use?	Cross-sectional study with participants that were 9–10 years old at baseline. (n=11878).	This study highlights a significant association between extreme heat exposure and early puberty initiation at ages 9–10, with subsequent links to behavioural problems and tobacco use.
Anderko L, Pennea E. Climate Changes Children's Health: Improving Clinical Practice to Address Changing Health Needs. <i>J Nurse Pract.</i> 2022;18(4):395–8.	United States	Translate evidence on climate change impacts on children into anticipatory guidance for pediatric nurse practitioners.	Clinical review of studies with children and adolescents in pediatric care.	Links climate stressors (heat, floods, wildfire smoke, CO ₂) to asthma, allergies, vector-borne disease, neurodevelopmental and mental health effects.
Granes L, Essers E, Ballester J, Petricola S, Tiemeier H, Iniguez C, et al. Early life cold and heat exposure impacts white matter development in children. <i>Nat Clim Change.</i> 2024;14(7).	Netherlands	Does exposure to cold and heat during early life affect white matter microstructure in children?	Longitudinal cohort study of children from the Generation R birth cohort (n = 2681).	Cold exposure during pregnancy and infancy, and heat exposure during infancy and toddlerhood, are associated with reduced myelination. No associations were found for FA. Children in low SES neighbourhoods were more vulnerable.
Bellanger M, Demeneix B, Grandjean P, Zoeller RT, Trasande L. Neurobehavioral Deficits, Diseases, and Associated Costs of Exposure to Endocrine-Disrupting Chemicals in the European Union. <i>J Clin Endocrinol Metabol.</i> 2015;100(4):1256–66.	EU (France, Denmark, US authorship)	To estimate the neurodevelopmental burden and economic costs in Europe that can be reasonably attributed to exposure to endocrine-disrupting chemicals (EDCs).	Quantitative model + expert panel synthesis.	EDC exposures in Europe contribute substantially to neurobehavioral deficits and disease, with a high probability of €150 billion costs/year.

<p>Denicola N, Lasher E, Bakemra A, Joglekar R, Zhang J, Hasenburger A, et al. FIGO committee opinion: Environmental drivers of obstetric health and early childhood development. Int J Gynecol Obstetr. 2025.</p>	<p>Global, FIGO (International Federation of Gynaecology and Obstetrics)</p>	<p>To provide a comprehensive synthesis of scientific evidence on how environmental toxicants—including air pollution, endocrine-disrupting chemicals (EDCs), heavy metals, and climate-related stressors—affect reproductive, perinatal, and early childhood outcomes.</p>	<p>Systematic review</p>	<p>Prenatal air pollution exposure (especially PM_{2.5} and NO₂) is consistently linked to autism spectrum disorder and cognitive impairment. Heavy metals (lead, mercury, cadmium) remain potent prenatal neurotoxins causing lifelong deficits.</p>
<p>Lafortune S, Laplante DP, Elgbeili G, Li X, Lebel S, Dagenais C, et al. Effect of Natural Disaster-Related Prenatal Maternal Stress on Child Development and Health: A Meta-Analytic Review. Int J Environ Res Public Health. 2021;18(16).</p>	<p>Canada</p>	<p>To quantify the effects of prenatal maternal stress (PNMS) caused by natural disasters on multiple domains of child development and health.</p>	<p>Meta-analytic systematic review of 37 studies (qualitative synthesis), 30 studies (meta-analysis).</p>	<p>Prenatal stress disrupts neurodevelopment. Consistent deficits in cognitive, motor, socio-emotional, and behavioural domains mirror the adverse neurodevelopmental outcomes observed in climate-stress-affected populations.</p>
<p>American College of Obstetricians and Gynaecologists, Practice GCoO. Reducing Prenatal Exposure to Toxic Environmental Agents: ACOG Committee Opinion, Number 832. Obst Gynae. 2021;138(1): e40–e54.</p>	<p>USA</p>	<p>To integrate more recent literature regarding reducing pre-pregnancy and prenatal toxic environmental exposures.</p>	<p>Clinical guidance document, no defined sample size.</p>	<p>Consistent deficits in cognitive, motor, socio-emotional, and behavioural domains mirror the adverse neurodevelopmental outcomes observed in climate-stress-affected populations.</p>
<p>Lin L-Z, Chen J-H, Yu Y-J, Dong G-H. Ambient air pollution and infant health : a narrative review. eBioMedicine. 2023;93.</p>	<p>China</p>	<p>To summarize recent evidence on how ambient air pollution affects infant health outcomes, including prenatal and early postnatal exposures.</p>	<p>Systematic review, no defined sample size.</p>	<p>Prenatal exposure to PM_{2.5} and NO₂ is associated with lower psychomotor, cognitive, and language scores at 15–24 months.</p>
<p>Yu T, Zhou L, Xu J, Kan H, Chen R, Chen S, et al. Effects of prenatal exposures to air sulphur dioxide/nitrogen dioxide on toddler neurodevelopment and effect modification by ambient temperature. Ecotoxicol Environ Saf. 2022;230.</p>	<p>China</p>	<p>To determine how prenatal exposure to sulphur dioxide (SO₂) and nitrogen dioxide (NO₂) affects toddler neurodevelopment, and to examine whether ambient temperature modifies these effects.</p>	<p>Prospective birth cohort study with 225 mother–child pairs.</p>	<p>Elevated prenatal exposure to ambient sulphur dioxide (SO₂) and nitrogen dioxide (NO₂) was linked to poorer neurodevelopmental outcomes in early childhood. The sensitive periods of vulnerability appeared to occur during the first and third trimesters for SO₂, and primarily during the third trimester for NO₂. Moreover, temperature acted as an effect modifier, as lower average temperatures throughout pregnancy intensified the adverse influence of SO₂ exposure on toddlers' language acquisition and adaptive behaviour development.</p>
<p>Conroy RM, Golden J, Malone C. Rethinking professional boundaries: The climate crisis and brain health. BJPsych Bull. 2025;49(1).</p>	<p>Ireland</p>	<p>How does the climate crisis—particularly air pollution—impact brain health, and what professional and disciplinary shifts are needed within healthcare to address this challenge effectively?</p>	<p>Conceptual and advocacy-oriented editorial. No primary data or specific population studied.</p>	<p>Noise pollution (from transport) is associated with poorer cognitive performance and school attainment in children. Exposures in utero to fine particulate matter and nitrogen dioxide are associated with deficits in cognitive and psychomotor development in children. These effects are evident as early as 15 months.</p>
<p>Polemiti E, Hesse S, Schepanski K, Yuan J, Schumann G. How does the macroenvironment influence brain and behaviour—a review of status and future perspectives. Mol Psychiatry. 2024;29(10):3268–86.</p>	<p>Germany and China</p>	<p>To provide a comprehensive overview of the existing evidence between the macroenvironment and the structure and functions of the brain, with a particular emphasis on its implications for mental illness.</p>	<p>Systematic narrative review</p>	<p>Air Pollution is associated with structural brain changes, linked to increased risk of depression, anxiety, schizophrenia, and cognitive decline. Prenatal and early-life exposure affects neurodevelopment (e.g., corpus callosum, limbic system, prefrontal cortex). High temperatures and humidity are associated with increased risk of depression, anxiety, suicide, and mental health-related hospitalisations. Extreme weather events (e.g., floods, droughts) linked to PTSD, depression, and anxiety. Limited neuroimaging evidence: simulated heat exposure linked to altered activation in PFC and impaired cognitive performance</p>
<p>Landrigan P, Fuller R, Fisher S, Suk W, D Sly PD, Chiles TC, et al. Pollution and children's health. Sci Total Environ. 2019; 650:2389–94.</p>	<p>United States</p>	<p>Comprehensive analysis of pollution and its effect on human health and global economy.</p>	<p>Review of articles which included children (0-19 years old).</p>	<p>Environmental pollution is a major contributor to child mortality. Notably, two-thirds of these fatalities occurred in children under the age of five. The burden of pollution-related mortality is disproportionately borne by low- and middle-income countries, which account for approximately 92% of these deaths. The primary causes are respiratory and gastrointestinal illnesses, largely resulting from exposure to polluted air and contaminated water sources. Beyond acute disease, pollution has also been increasingly linked to a growing number of non-communicable diseases (NCDs) in children, reflecting a concerning upward trend in chronic health conditions. Addressing pollution through preventive strategies presents a significant opportunity to reduce disease burden and promote healthier developmental outcomes in children worldwide.</p>

This section provides a concise overview of the associations identified between these climate-related factors and child neurodevelopment.

Air pollution

At the neuroanatomical level, the hippocampus appears particularly vulnerable to air pollution. Prenatal exposure to PM_{2.5} during the third trimester has been associated with reduced hippocampal volume growth. Altered hippocampal development may have behavioural consequences; for example, a larger right hippocampal volume has been linked to increased externalizing symptoms around age of ten (2).

Prenatal and postnatal exposure to traffic-related air pollution and PM_{2.5} has also been associated with higher risks of autism spectrum disorder, attention deficit/hyperactivity disorder (ADHD), and lower IQ. Several mechanisms have been proposed to explain these effects. Prenatal PM_{2.5} exposure is linked to decreased levels of synapsin I, a synaptic protein essential for neurotransmitter release, potentially disrupting neural communication (5-8). Attention and behavioural difficulties may also arise from altered maturation of the default mode network and attention networks, both critical for cognitive and emotional regulation (9).

Beyond cognitive functions such as memory and learning, motor and sensorimotor abilities have also been shown to be adversely affected by air pollution exposure (10,11).

Although more research is needed, evidence from a London-based longitudinal cohort indicates that increases in outdoor ozone exposure may impair executive function development in adolescence (12). Importantly, rising levels of ozone and particulate matter, exacerbated by climate change, can worsen respiratory conditions such as asthma and reduce oxygen availability to the brain, further compromising cognitive development (13).

Extreme temperatures

Heat exposure during early development, particularly from the second trimester of pregnancy to seven months postpartum, has been associated with poorer language outcomes in young children (14). Even heat exposure during the very early prenatal period (weeks 0-3) has been linked to an increased risk of cerebral palsy (15).

In a U.S. cohort of 8,120 children aged 9–12 years, it was found that a higher number of days with temperatures above 32.2 °C was linked to an increase in externalizing behaviours (16). Exposure to extreme heat has also been linked to higher levels of individual delinquency and tobacco use among children, potentially due to physiological stress responses that impair cognitive functioning and self-regulation (17,18). Altered prefrontal cortex activation and reduced cognitive performance may offer additional explanatory pathways (19). Furthermore, extreme heat exposure has been associated with reduced learning, memory, and overall cognitive performance in children aged 9-10 years (20,21). Not only heat but also cold temperatures during pregnancy and the postnatal period has been associated with reduced myelination (22).

Natural disasters

Natural disasters constitute a major climate-related stressor affecting neurodevelopment through both direct physiological stress mechanisms and indirect pathways, such as disrupted nutrition, housing instability, and reduced access to healthcare. Adequate nutrition in the postnatal period is essential, and early childhood malnutrition is strongly linked to adverse neurodevelopmental outcomes (13). A critical developmental window appears to be around age two, when exposure to drought, flooding, or other extreme weather events can have long-term neurocognitive consequences, including reduced cognitive abilities in adulthood. Insufficient nutrition during this period

may impair dendritic formation and myelination, key processes supporting healthy neurodevelopment and learning (23).

In addition to nutritional deficits, the psychosocial stressors associated with natural disasters, such as displacement, food insecurity, and heightened family stress, have been linked to emotional and behavioural difficulties in affected children (24).

Endocrine disrupting chemicals

EDCs, including phthalates, bisphenols and per- and polyfluoroalkyl substances (PFAS), can interfere with thyroid hormone signalling, a process essential for normal brain maturation. Environmental shifts associated with climate change, such as rising temperatures and extreme weather events like floods and heatwaves, may further increase human exposure to these compounds. EDC exposure has been shown to trigger neuroinflammation, oxidative stress, and epigenetic alterations, ultimately disrupting neurodevelopment and impairing cognitive functioning. According to the FIGO Committee Opinion, exposure to EDCs contributes substantially to the burden of neurobehavioral disorders in Europe, with societal costs estimating to exceed €150 billion annually (6,25).

Discussion

The objective of this review was to map the existing evidence on the effects of climate change on neurodevelopment. The literature indicates that several climate-related domains, including temperature changes, air pollution, and natural disasters, affect neurodevelopment through multiple biological and psychosocial pathways. A consistent finding across studies is that individuals with lower socioeconomic status and limited resources are disproportionately affected by climate change and its neurological consequences. Although climate change encompasses various subdomains, we restricted our focus to studies explicitly addressing “climate change”. This strategy enabled a coherent overview of its diverse impacts, while acknowledging that some relevant studies may not have been captured, for example, those focusing exclusively on “air pollution” or “heat waves”. Given the broad scope of the topic, narrowing the search to climate change terminology also reduced the total number of articles requiring screening.

Another important consideration is that the term “neurodevelopment” is interpreted variably across studies. While it may refer to anatomical brain development or developmental disorders, some authors include broader mental health outcomes. Articles that addressed mental health without linking outcomes to brain development or climate-related exposures were therefore excluded. Likewise, we did not include specific diagnostic terms such as “autism” or “ADHD”, which likely resulted in the omission of certain relevant publications.

It is also essential to recognize that climate change represents only one of many environmental factors influencing neurological development. Exposure to toxic chemicals, plastics, light and noise pollution, urbanization, socioeconomic disadvantage, and reduced access to green spaces can all significantly affect brain development (6). As discussed above, climate change may exert substantial effects on neurodevelopment, contributing to increased psychological, social and economic burdens for children and society. These impacts should be considered in future policymaking, with particular attention to vulnerable populations who bear the greatest risk. Further research, both international and locally focused, is necessary to strengthen the evidence base. For instance, in Belgium, it would be valuable to investigate whether climate change-related exposures are associated with differences in the prevalence of neurodevelopmental disorders between urban and rural regions. Such findings could guide policy and resource allocation.

In conclusion, climate change is likely to have long-term consequences for child development, extending beyond physical health to influence cognitive functioning, social participation, and overall well-being.

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