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Climate Change, Air Pollution, and Children's Mental Health

Introduction

Climate change and air pollution are two of the most pressing global public health challenges and have significantly linked causes and shared solutions.[1] Emissions from fossil fuel combustion are a major threat to children's health and future, and a major contributor to environmental injustice and global inequality.[2] Carbon dioxide (CO_2), the main driver of climate change, and other toxic particles emitted from burning fossil fuels exert direct and indirect adverse effects on the environment and children's physical and mental health.[3] Young children and adolescents, especially those with social and economic disadvantages, are one of the most at-risk populations.[2] According to the World Health Organization (WHO), 88% of the global burden of disease attributable to climate change occurs in children under the age of 5 years.[4,5] The United Nations International Children's Emergency Fund (UNICEF) has estimated that about 503 million children worldwide reside in areas at extremely high risk of extreme weather events due to climate change, and has projected that by 2040, 1 in 4 children will live in areas of severe water shortage.[6] Of related importance, globally, it is estimated that 93% of children under the age of 15 years currently are exposed to ambient fine particulate matter levels above WHO air quality guidelines, including 630 million children under the age of 5.[7]

Worldwide, 10-20% of children and adolescents are affected by mental health problems, and some data suggest that the burden may be increasing.[8,9] A small but growing body of literature has found that the direct effects of climate change, such as extreme weather events, increasing temperature, and environmental changes, and the indirect effects, such as forced migration and nutrition insecurity, can increase children's mental health risks. These include post-traumatic stress disorder (PTSD), depression, anxiety, phobias, sleep disorders, attachment disorder, substance abuse, and predisposition to adverse mental health outcomes later in life.[10-12] Likewise, emerging research shows that exposure to increased levels of air pollutants contributes to the etiology and worsening of mental health conditions.[13] Moreover, the impact from climate change and air pollution starts early in the prenatal period and can alter healthy neurological and physiological development; therefore, the mental health burden in children is aggravated at multiple stages.[10,14-16]

Worse yet, the climate change – air pollution interaction can result in a vicious cycle detrimental to children's mental health. The emission sources and some air pollutants themselves are causes of climate change, while climate change impacts air quality through multiple pathways. Climate change and air pollution can synergize and amplify adverse mental health outcomes. However, compared to the scientific evidence for the effects in adults, the understanding of such effects in young people is less robust. There is an urgent need to address this neglected field and address the impact that air pollution and climate change have on children's and adolescents' mental health. This will entail developing and implementing policies and specific actions based on current evidence. In the meantime, establishing a scientific base is necessary to support and guide such efforts. This includes knowledge about ways to influence climate change and air pollution, and the etiology, prevention, and treatment of associated child and adolescent mental health effects.

In this article, we summarize what is known about how climate change and air pollution, singly or in combination, affect children and adolescents' mental health; outline a research agenda concerning these critical issues; and propose a series of public health policies and recommendations to address the problem.

Mental Health Impacts of Climate Change on Children and Adolescents

Climate change affects mental health directly by exposing people to traumatic events, and indirectly by affecting physical health, well-being, and societal and economic structures.[17-19] Different from adults in their developmental stages and physiological and psychological characteristics, children and adolescents are particularly vulnerable to these adverse effects; however, the scientific evidence for mental health impacts of climate change on children and youth is scarce.[20,21] It is estimated that up to 175 million children worldwide will be affected by weather disasters related to climate change in the next decade.[22] Worse yet, young people already living in disadvantage due to geographical location and climate, social infrastructure, and socioeconomic status are likely to be more severely impacted, exacerbating existing health inequities.[10]

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Extreme Weather Events

Extreme weather events, such as floods, hurricanes, heatwaves, and forest fires, and the accompanying environmental changes and consequent disruption to family and social networks are associated with increased risk of various long-term and short-term childhood mental health effects, such as PTSD, stress, depression, anxiety, phobias, panic attacks, attachment disorders, sleep disorders, adjustment disorders, and substance abuse.[10,17,23,24] Compared to adults, children have a higher prevalence of PTSD, higher severity of distress, and slower recovery from mental trauma after extreme climate events.[25-29] Childhood and adolescent trauma and PTSD symptoms have been linked to cognitive deficits, impaired verbal IQ, and elevated risk of dementia in older age.[29-31] In addition, separation from caregivers; loss of social support networks; changes in food availability, water supplies, and shelter conditions; and disruptions to the education system can cause acute shock and trauma and present other negative long-term impacts.[26,29,32,33]

Incremental Environmental Changes

In children, the mental health effects from incremental environmental changes, such as prolonged heat and droughts, altered precipitation patterns, and rising sea levels, are not well-elucidated. Despite the gaps in epidemiological evidence for chronic environmental adversity, repeated stressful early-life events are expected to create a predisposition to future psychiatric disorders and affect learning and memory processing.[10,17,34]

Incremental climate changes are very likely to result in alterations in natural landscapes, disruption of food and water sources, deterioration of living conditions, financial stress, elevated risk of violence and crime, infectious disease outbreaks, and displacement, posing myriad threats to the mental health and well-being of children and adolescents.[10,29,35] Early-life environmental chaos, particularly for low-income children, is suggested to impede mental health and development.[36] Furthermore, studies indicate that children and adolescents faced with forced displacement, relocation, and disruption in their education experience emotional disturbance, behavioral problems, poor family functioning, and social insecurity.[37] The psychological distress these changes impose on the parents can affect the mental health of children and adolescents.[38]

Eco-Anxiety

The global climate crisis has also triggered eco-anxiety, “a chronic fear of environmental doom” according to the American Psychological Association, or more broadly, mental distress and anxiety associated with worsening environmental conditions or the ecological crisis, particularly in children and youth.[39] Even among people whose personal well-being has not been affected by climate change, information from the mass media and the anticipated future loss can cause distress and grief.[40,41] The psychological effects remain to be further studied and characterized. However, some people have reported panic attacks, loss of appetite, insomnia, and obsessive thinking.[42] A growing body of studies shows that children and youth report greater concern and are more likely to accept the scientific communications about climate change compared with adults.[10,43] Mental health professionals caring for adolescents have observed eco-distress, with symptoms of low mood, helplessness, anger, losing sleep, panic, and guilt.[44] Studies show that most surveyed children and teenagers in the US express fear, sadness, or anger about the climate crisis.[43,45] Narratives about climate change in the media, influence from peers, and ubiquitous negative publicity on environmental issues remind young people of the ongoing climate crisis. For some, the information influx can be difficult to handle.[46]

Although eco-anxiety itself is expected and not considered a discrete psychiatric condition, it may evolve in nature and severity, having adverse effects on the mental health and functioning of healthy children and adolescents. It may have similar effects and increase the severity of pre-existing physical and mental health problems.[43] Children and adolescents are more vulnerable to chronic stress and everyday anxiety given their unique and critical developmental stage.[47] Yet, there is limited information on the short-term and long-term mental health effects of eco-anxiety on children in this population.

Mental Health Impacts of Air Pollution on Children and Adolescents

Air pollution exposure induces a wide range of adverse health effects in the human body, including respiratory and cardiovascular disease.[48] Accumulating research demonstrates that air pollution, directly and indirectly, may increase the risk of mental health disorders; however, the evidence is less robust, particularly in children and adolescents.[13,49,50] Children are uniquely vulnerable to the effects of air pollution: their airway defenses against air pollutants are not fully developed; they have a higher

intake of air and resting respiratory and metabolic rates compared with adults; and they spend more time outdoors, which increases their degree of exposure.[51]

One posited biological mechanism for the link between air pollution exposure and mental health problems is that exposure to air pollution induces neuroinflammation, and affects cognition and behavior, as suggested by several animal and human studies.[52,53] The brains of otherwise healthy children and adolescents from very polluted cities who experienced sudden death have biomarkers of neuroinflammation, altered innate immunity, and accumulation of cerebrospinal fluid neurodegenerative disease biomarkers such as Aβ42 and α-synuclein, also found in patients with Alzheimer's and Parkinson's diseases.[54] Early-life exposure to ambient air pollution may contribute to the etiology and worsening of neurodevelopmental disorders, including childhood attention-deficit/hyperactivity disorder (ADHD) and autism spectrum disorder (ASD), and reductions in IQ.[3,55-58]

Scientific evidence on non-developmental mental illnesses is scarce.[50] Besides the neurodevelopmental effects, prenatal exposure to airborne polycyclic aromatic hydrocarbons (PAHs) has been associated with childhood anxiety and depression.[57] A cohort study in Denmark reported that higher exposure to nitrogen oxides, a common marker for traffic-based air pollution, during childhood was associated with a higher subsequent risk for schizophrenia.[59,60] Similarly, a recent study in the United Kingdom demonstrated exposure to nitrogen oxides in childhood and adolescence to be associated with psychopathology later in life, consisting of greater internalizing, externalizing, and thought disorder symptoms.[61] Higher exposure to nitric oxide is reported to be associated with a higher frequency of prescription antipsychotic and sedative medications both in children and adolescents.[62] In addition to nitrogen oxides, outdoor exposure to particulate matter has been associated with increased odds of psychotic experiences during adolescence.[63]

There is a positive association between air pollutants, such as particulate matter (PM), nitrogen dioxide (NO_2), and ground-level ozone (O_3), and increased risk and worsening of depression in adults. However, in children and adolescents this needs further investigation.[13,50] One study in European cohorts did not observe associations between prenatal and postnatal air pollution and depression, anxiety, or aggressive behavior

symptoms.[64] Contrastingly, a study in the US found that early-life and childhood exposure to traffic-related air pollution was associated with self-reported symptoms of depression and anxiety at age 12.[65] Increased odds of major depressive disorder at a later age from air pollution exposure has been reported in children from a UK longitudinal cohort study, with elevated odds of conduct disorder as well.[66]

Air pollution also impacts people's physical well-being, increasing rates and severity of mental health problems. Families with children with physical health problems are at increased risk of mental health problems.[67] Adverse physical health impacts such as asthma exacerbations increase school absences, thereby contributing to diminished academic performance, affecting virtually every aspect across the lifespan.[3] Additionally, chronic physical health conditions are major risk factors for mental health problems, as well as the overall quality of life.[68] The direct and indirect mental health outcomes of air pollution exposure during childhood are yet to be fully understood.

The Climate Change – Air Pollution Interaction and Mental Health

Both climate change and air pollution are driven mainly by fossil fuel combustion and impose substantial health burdens. In combination, they may have synergistic effects and increase vulnerability, resulting in a vicious cycle detrimental to children's mental health.

Elevated temperatures affect O_3, PM, and NO_2 levels.[69,70] An increase in temperature contributes to higher emissions of both anthropogenic and biogenic precursors for O_3 formation.[1] Simultaneously, the altered ecosystem feedbacks during drought and heatwaves, for example, the reduced ozone removal by vegetation, magnify ozone air pollution.[71] Heatwaves are also accompanied by high concentrations of air pollutants due to reduced wind speed and rainfall.[72] During heatwaves, the increased demand for electricity increases power plant emissions including PM and heat-absorbing black carbon, thus further increasing local temperatures.[1,73,74]

Alterations of weather patterns resulting from climate change may have substantial impacts on the temporal and spatial distribution of air pollutants, their dispersion, dilution, transformation, and deposition.[75]

Changes in wind speed, direction, and surface air mixing patterns may result in air stagnation and increased levels of pollutants at ground level. Alterations in precipitation and humidity also influence the removal of air pollutants The increase in wildfires and dust storms, longer pollen seasons, and mold proliferation resulting from climate change are also detrimental to air quality.[1,73,76]

At the population level the interaction between air pollution and elevated temperatures can lead to increased non-accidental mortality.[77] It is expected that the synergistic effects between air pollutants and heat stress amplify the adverse mental health impacts, especially in at-risk populations. Studies have reported links between air pollution, new or exacerbated mental disorders, and emergency room visits or hospitalizations.[13,78] Air pollution and temperature variability are associated with increased odds for mental health problems in adults.[79] Nevertheless, to date no study has examined such effects in children and adolescents.

Approximately 40% of the world's children live in informal settlements in urban areas. This number is expected to rise as urbanization and industrialization accelerate, especially in low- and middle-income countries.[80] Urban and metropolitan areas, where built structures are concentrated and green space is limited, experience an elevated temperature compared with outlying rural areas. These temperature differences, or the heat-island effect, are disproportionately impacting communities of color, low-income, or otherwise marginalized groups.[81] The urban heat-island effect can aggravate the negative impact of air pollution and heatwaves on mental health.[82]

The adverse health effects of air pollution and climate change on children start early during the prenatal period.[15] Maternal stress – directly from climate change, natural disasters, extreme weather events, and rising temperature, and indirectly from displacement, malnutrition, sanitation issues, increased risk of infectious diseases, and eco-anxiety – can shape fetal programming, induce epigenetic modification, and cause long-term effects. These can predispose children to neurodevelopmental conditions, such as ADHD and ASD, mood disorders, behavioral and motor problems, reduced IQ, impaired language development, and schizophrenia.[10,15] Similarly, maternal air pollution exposure is a potential risk factor for ASD and ADHD, lower IQ, and reductions in self-regulation

and academic achievement.[83-86] The continued exposures to climate change and air pollution and their interaction throughout the life of the child will further exacerbate the adverse mental health impacts.

Overall, it is difficult to assess the multidimensional mental health effects climate change and air pollution exert on children. Better evidence and quantitative analysis are urgently needed to assess critical issues and suggest changes to individual behavior, parental practice, and social policy.

Knowledge Gaps

Although limited, the existing research shows that the interplay between air pollution and climate change can inflict adverse mental health outcomes in children and adolescents. However, substantial knowledge gaps need to be addressed to better understand the risk and underlying mechanisms, assess the co-benefits from reducing anthropogenic air pollution, and develop mitigation strategies.

Climate Change and Children's Mental Health

Studies exploring the mental health impact of climate change in children and adolescents have focused mainly on the short-term effects of extreme weather events. However, long-term accumulating environmental risk factors may bring slower-onset chronic, more sustained, and severe impacts across the lifespan.[8,10] To date, the pre-disaster heightened anxiety level, and hopelessness due to the perceived risk of incremental environmental changes have been rarely considered.[35] The link between the gradual degradation of the environment and mental health outcomes is also missing.[87] Evaluation of the impact of these insidious environmental changes in vulnerable children and adolescents from low-income countries is vital.[88] Further studies using high-resolution meteorological and geospatial data and standardized mental health measurements are needed to define, characterize and quantify the mental health outcomes over longer time. Quantitative assessments of the mental health impacts from climate change needs to be developed and validated. Moderating and mediating factors should also be evaluated to understand the underlying mechanisms and pathways, and to provide evidence for prevention and policymaking.

It is also necessary to assess how overarching climate awareness and concerns affect children's mental health and well-being.[21] There is limited information about the impacts of measures to decrease eco-anxiety, such as environmental actions.[89] To quantitatively evaluate eco-anxiety, a standardized scale needs to be developed and applied in future studies. Attention should be paid to explore how children's climate-change-related communications and social engagement activities impact their mental health and well-being. Additionally, more information also needs to be collected to assess the responses from adults regarding children's environmental activities and their effects.

A systems thinking approach considering proximate, intermediate, and distal harm linking climate change and mental health conditions should be used in future research to organize better, disentangle, and interpret the growing information.[90] The economic costs and co-benefits can further be evaluated based on the scientific evidence.

Air Pollution and Children's Mental Health

There is limited research on the mental health effects of air pollution in children and adolescents despite their vulnerability.[50] More epidemiological data are therefore needed to quantitatively assess the increased mental health risk from prenatal, childhood and adolescent air pollution exposure.

In the meantime, more toxicological and clinical research are necessary to understand the mechanisms how air pollution contributes to elevated risk of mental health disorders. The underlying biological pathways and the role of neuroinflammation must be examined to understand and implement preventive measures. Moreover, the specific constituents, types and sources of air pollutants and how they affect mental health should be explored to gain information for the revision of environmental regulation policies.

A multidisciplinary approach employing clinical, neurophysiological, and epidemiological evidence will be necessary to establish the causal association between air pollution exposure and mental health effects in children and adolescents.[49] The negative mental health impacts associated with physical health effects such as chronic diseases and school absence should be brought to attention. To provide knowledge for policy and intervention, future studies to evaluate the health co-benefits of

air pollution mitigation should consider direct and indirect children's mental health benefits for a more accurate benefit analysis.

Interactions of Climate Change and Air Pollution

The combined impact of air pollution exposure and climate-related environmental changes on children and adolescents' mental health must be researched.[1] So far, no study has investigated the synergistic interaction between air pollution and elevated temperatures on children's mental health. Large-scale epidemiological cohort studies using high-resolution meteorological and air pollution data, combined with quantitative assessment of children and adolescents' mental health status are needed to understand and quantify the problem. Special attention should be paid to children living in informal settlements in urban areas.

In general, models and data to evaluate the combined detrimental mental health effects of climate change and air pollution are currently lacking. Such assessments are necessary for both adults and children. Both quantitative analysis and modeling, and epidemiological evidence are needed to tackle the complicated interactions and provide insights relevant to future decision-making processes.[73] Particularly, the development of birth cohorts will provide opportunities to collect a wide range of environmental exposure and mental health information in the long term, and elucidate the complex multidimensional mental health effects from climate change and air pollution.

A better quantitative assessment of the short- and long-term mental health co-benefits from efforts for climate change mitigation and air pollution regulation is needed to support the implementation of public health-based policies.[91] It would also be beneficial to explore the attributable contributions from prenatal exposures to predisposition and long-term mental health risk. It is crucial for future cost-benefit analysis of air pollution and climate change interventions to consider the mental health aspects more comprehensively.

Public Health Policy Implications

Listed below are four public health policy recommendations regarding the known and potential mental health effects of air pollution and climate change on children and adolescents.

1) Raise public awareness of the effects of air pollution, climate change, and their interaction on child and adolescent mental health. Such public awareness is fundamental to prioritize policies, investment, and research, and to facilitate both climate change actions and public mental health promotion programs. Education programs should be implemented to recognize the impact and prioritize climate change action, especially in high-income countries, which are the main drivers of climate change. Additional mental health education and help should be made available primarily in low-income countries, where stigma, biased cultural values, and lack of resources pose additional challenges.[92] Relevant educational materials and training should be part of the education process of local health professionals to help them understand mental health risks and improve the care of affected individuals. It is important to provide local health and educational professionals, parents, and, most important, children with relevant information to overcome the stigma and cultural biases regarding mental disorders.[93] National and local government agencies and intergovernmental and nongovernmental organizations must participate and provide expertise, funding, services, support, and education. Addressing the mental health needs of children and adolescents will require intensive, extensive, and extended advocacy to develop and sustain the political will and social strategies needed.

2) To minimize the associated potential health risk, exposure to environmental risk factors should be prevented or reduced, especially for at-risk populations. In general, governments should ensure that schools are safe, resilient, and in secure structures at sound locations; schools should design risk management plans and prepare students for disaster response. For low- and middle-income countries, city governments should work with community organizations and support residents in implementing and upgrading programs and building resilience.[94] These programs should be assessed with established standards to ensure the safety of housing structures and improve infrastructure, including water supply, sanitation, wastewater and flood drainage, and electricity. In high-income countries, school buildings should be equipped with adequate ventilation, air conditioning, and effective early-warning systems. Some experiences can

be learned from environmental health practice in schools amid the Covid-19 pandemic, including but not limited to the monitoring and assessment of indoor environmental conditions, implementation of high energy efficient ventilation systems, and periodic screening of children's health conditions. Consideration should be given to relocating communities in areas at risk of extreme weather events and schools close to heat sources and traffic or industrial air pollution.

3) Climate change preparedness is critical for communities disproportionally impacted. Despite the efforts to reduce exposure, the mental health impacts cannot be entirely prevented; a plan is therefore needed to reduce people's vulnerability and mental health risk when climate disasters occur. Long-term psychological and social support strategies designed specifically for children and adolescents must be developed and implemented. Schools, religious institutions, and community groups need to be encouraged and empowered to support children and their families. It is also beneficial to discuss scenarios in which mental health support may become less available, such as forced migration, so children and their families are aware of and prepared for potential adverse impacts.[95]

4) Children and adolescents' expression and discussion of climate-related anxiety should be encouraged, and their feelings should be acknowledged. Climate anxiety in children and adolescents is a collective result of their climate-change-related physical and psychosocial experiences, and the responses from those in positions of power are important. Thus, a social discourse where expressions are respected, validated, and acted upon by each other, and by those who they depend on can be beneficial. Child health professionals, parents, and teachers can also encourage children to take feasible actions, such as learning about climate change, reducing household carbon footprint, or advocating responsibility and sounding clarion calls about the urgency of such efforts for their future lives and life on our planet. Unfortunately, children and adolescents all too frequently are not included in the development of practical age-specific educational and motivational messaging, thereby missing input about crucial strategies while also missing the opportunity for active engagement that such involvement encourages.

The mental health effects of climate change and air pollution in children and adolescents need urgent attention. Concerted efforts from

the scientific, public health, and medical communities, leaders, and decision-makers of government and nongovernment organizations are needed to develop harmonized clean air and climate change mitigation policies that protect the mental health and well-being of our children and adolescents.

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