Impacts of Extreme Weather Events on Education Outcomes: A Review of Evidence

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Extreme weather events are increasingly disrupting schooling. Yet, these are underrepresented in the climate change literature. Of 15 review articles on the economic impacts of climate change published since 2010, only three mention the impacts of climate change on education. We review available literature on the effects of weather extremes on education. We outline key pathways through which these events impact education outcomes, as well as the magnitude of those impacts. Evidence implies a significant and adverse relationship between heat and learning. Studies suggest surpassing a high temperature threshold makes learning difficult and results in learning losses. Across studies, each additional day subject to extreme heat reduces learning. Tropical cyclones, floods, and wildfires precipitate school closures, which halt learning. Evidence suggests that one day of school closures leads to one day of learning lost. Weather extremes also negatively impact education outcomes through health, nutrition, poverty, and fragility, among other distal pathways. We discuss the implications of this evidence for policy, including the need to adapt education systems to climate change. Mitigation and adaptation are both urgently needed as extreme weather events become more frequent and severe in the context of climate change.

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Introduction

Human activity, primarily through the release of greenhouse gases, is indisputably causing climate change. In 2011–2020, global surface temperature was 1.1°C above the levels seen in preindustrial times (Bashmakov et al. 2022). The release of green-

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house gasses—driven by unsustainable energy use, land use, as well as consumption and production patterns—has persistently risen (IPCC 2023). Unsurprisingly, high-income countries bear most of the responsibility for these emissions. Consumption-based emissions data shows that high-income countries are responsible for 92 percent of excess global CO2 emissions (Hickel 2020). More specifically, the top decile of households with the highest per capita emissions contributes 34–45 percent of global consumption-based household greenhouse emissions, compared to 13–15 percent contributed by the bottom 50 percent (IPCC 2023). However, the consequences of these emissions will be more severe and impactful in developing countries (Das Gupta 2014; Sun et al. 2019). Even within countries, the most vulnerable states and communities will be the hardest hit by climate change, exacerbating existing inequities (Kemp et al. 2022).

Climate change is increasing the frequency and intensity of extreme events such as floods, droughts, and wildfires, as well as the probability of co-occurring events (Stott 2016; Ebi et al. 2021). The number of disasters has increased by a factor of five over a 50-year period and weather, climate, and water hazards accounted for 50 percent of all disasters over this period (WMO 2021). Approximately 93–95 percent of the world population will experience more than double the current number of hot and dry events by the end of the twenty-first century (Ridder et al. 2022).

Children are particularly at-risk to the effects of climate change. Over 99 percent of children around the world are exposed to at least one major climate and environmental hazard, shock or stressor and nearly half of the world's children live in extremely high-risk countries for climate shocks (UNICEF 2021b). In the absence of climate change mitigation, there will be an additional 131,000 child deaths each year by 2030, driven by a higher burden of infectious diseases, food insecurity, and political instability (Williams et al. 2021). It is estimated that the education of 75 million children has been disrupted by crises such as conflict and natural disasters. These are projected to increase in frequency and severity with climate change (Theirworld 2018).

While the potential effects of climate change on children's health are relatively well-documented, there has been less systematic attention on the effects of climate change on children's education outcomes. Out of 15 review articles on the economic impacts of climate change published since 2010, only three mention the impacts of climate change on education.[1] On Web of Science, there are five-times as many publications on the health impacts of climate change as on the educational impacts of climate change. The regions of the world that are the most vulnerable to the impacts of climate change, such as sub-Saharan Africa and Southeast Asia, are those that have the least available evidence to quantify how education outcomes are and will continue to be affected. Out of the articles on education and climate, 33 percent (1,903 out of 5,732) are based in the United States and 78 percent (4,467) are from high-income economies (based on World Bank classifications).[2]

This paper reviews and summarizes current evidence on the impacts of extreme weather events on education outcomes. Focusing on extreme heat, tropical cyclones, floods, droughts, and wildfires, research on both the direct and indirect impacts of these extreme weather events on short-term and long-term educational indicators is reviewed. Implications of the evidence for the education sector are discussed. The paper also highlights evidence gaps and potential opportunities for future work on this topic. Extreme weather events will only become more severe under climate change; we must understand their impacts on education systems, schooling, and long-term economic context to best prepare and protect the populations and countries that are most vulnerable.

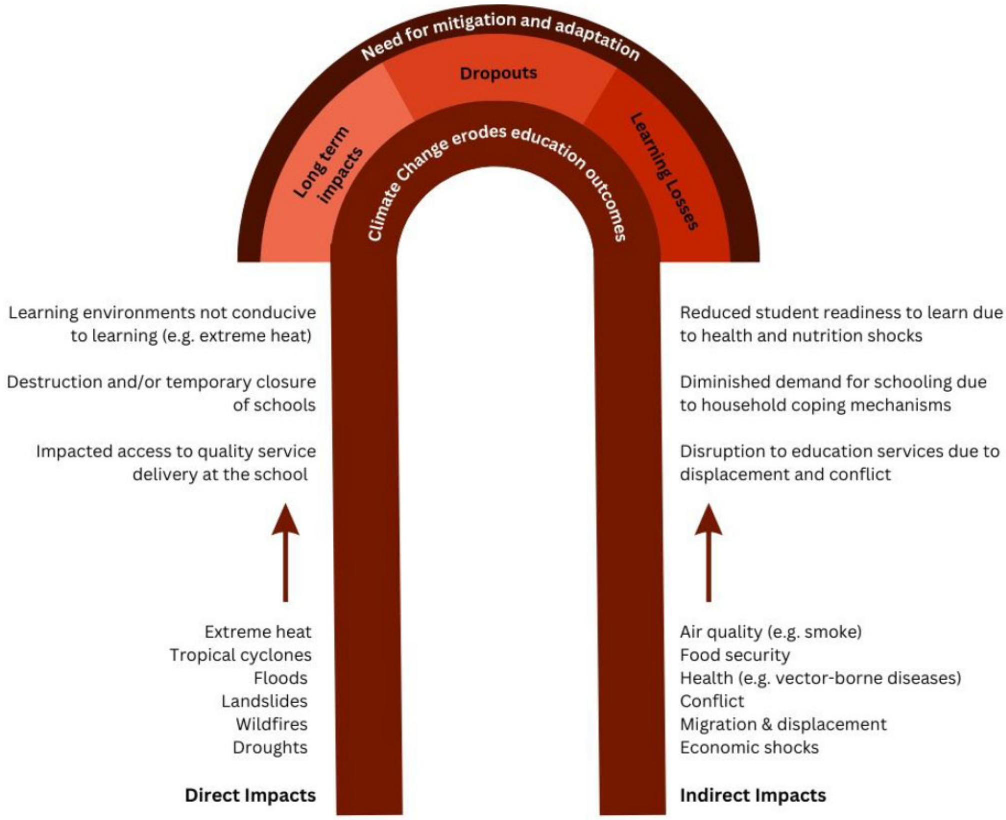
The paper is organized as follows. We first present a framework summarizing the direct and indirect ways in which extreme weather events impact education outcomes. Next, we summarize evidence on the impact of the four direct channels (extreme heat, tropical cyclones/floods, droughts, and wildfires) on learning, enrollment, dropouts, and long-term outcomes. After this, we present evidence on the indirect channels through which extreme weather events affect education outcomes. Next, we discuss how to protect and leverage the education sector in the face of climate change. The final section concludes.

Impacts of Climate Change on Education: Overview of Framework

Climate change erodes education outcomes by impacting learning, dropouts, and long-term outcomes (fig. 1). Extreme weather events have proximate, or direct, effects on education outcomes through compromised school access, school closures, destruction of school structures, and impacts on school environment (see table 1 for details on key papers included in the review).

There are also more distal, or indirect, effects of these climate extremes on education outcomes. Extreme weather can lead to economic shocks, produce poor air quality, increase conflict and food insecurity, and drive higher migration and displacement. Increasing extreme weather and climate events have already driven millions of people towards acute food insecurity and reduced water security, with the largest adverse impacts observed among the most vulnerable locations and communities (IPCC 2023). Climate change will produce more conflict and violence, especially in low-income regions of the world (Akresh 2016). For example, climate-driven food insecurity and water scarcity are projected to increase with increasing global warming, interacting with non-climatic risk drivers such as more frequent pandemics, conflicts associated with competition for resources (land, water), and forced displacements (IPCC 2023). These will exacerbate disruptions to education services, reduce demand for schooling due to coping mechanism to account for economic losses at the household level, and reduce the readiness of students due to health and nutritional shocks (Caruso et al. 2024). Poverty, food insecurity, and stress make populations more vulnerable to the effects

Figure 1. Impacts of Climate Change on Education Outcomes



Source: Author's illustration.

of extreme weather and measures to address these underlying vulnerabilities will not only address some of the root causes of educational disparities but can also increase resilience to climate hazards.

Extreme Heat and Education Outcomes

Extreme heat poses a threat to children and their education outcomes. Around 30 percent of the world's population is exposed to extreme heat conditions and future population exposure is projected to increase by 48 percent to 74 percent under differing climate change scenarios (Mora et al. 2017). Over one-third of children globally are currently exposed to heatwaves (UNICEF 2021a). The increasing exposure to extreme heat poses a notable challenge for the education sector. A growing body of evidence suggests that high temperatures can adversely impact both short-term and long-term academic performance.

Table 1. Key Literature on the Impacts of Extreme Weather on Educational Outcomes

Exposure	Title Author *Journal, Year*	Country	Student population	Study type	Key finding
High temperature	**Hot Temperature and High-Stakes Performance** R. Jisung Park *Journal of Human Resources, 2022*	United States	high school students	Observational	Taking an exam when the temperature is 90°F results in 13 percent of a standard deviation lower exam performance relative to a more optimal 75°F.
High temperature	**Learning is inhibited by heat exposure, both internationally and within the United States** R. Jisung Park, A. Patrick Behrer & Joshua Goodman *Nature Human Behavior, 2020*	58 countries	global- 15-year-olds (PISA), US- 3rd to 8th grade (SEDA)	Observational	For each additional hot day (defined as a day above 80°F) in the three years preceding the exam, learning is lowered by 0.0018 standard deviations.
High temperature	**Heat and Learning** R. Jisung Park, Joshua Goodman, Michael Hurwitz, Jonathan Smith *American Economic Association, 2020*	United States	high school (PSAT)	Observational	For 3 additional hot days (defined as 3 days above 90°F) in the year prior to the exam, learning is lowered by 0.002 standard deviations.
High temperature	**Temperature and high-stakes cognitive performance: Evidence from the national college entrance examination in China** Joshua Graff Zivin, Yingquan Song, Qu Tang, Peng Zhang *Journal of Environmental Economics and Management, 2020*	China	high school (National College Entrance Examination)	Observational	A 1°C increase in temperature during the exam period decreases total test scores by 2.91 percent of a standard deviation.

Table 1. Continued

Exposure	Title Author *Journal, Year*	Country	Student population	Study type	Key finding
High temperature	**The relationship between classroom temperature and children's performance in school** Pawel Wargocki, Jose Ali Porras-Salazar, Sergio Contreras-Espinoza *Building and Environment, 2019*	Global	Elementary to high school level	Review	Performance on psychological tests and school tasks can be expected to increase on average by 20 percent if classroom temperatures are lowered from 30°C to 20°C. Temperature for optimal performance is lower than 22°C in temperate climates.
High temperature	**Effects of Heat on Mathematics Test Performance in Vietnam** Tien Manh Vu *Asian Economic Journal, 2022*	Vietnam	high school (National college and university entrance examinations)	Observational	An increase of 1°F results in an approximate 0.006 standard deviation loss of in standardized test scores.
High temperature	**Heat and learning in elementary and middle school** Travis Roach, Jacob Whitney *Education Economics, 2020*	United States	elementary and middle school	Observational	Increasing average temperature levels and particularly hot days reduce student learning and achievement- each day above 100°F decreases average student achievement by 2.3 percent.
High temperature	**Classrooms' indoor environmental conditions affecting the academic achievement of students and teachers in higher education: A systematic literature review** Henk W. Brink, Marcel G. L. C. Loomans, Mark P. Mobach, Helianthe S. M. Kort *Indoor Air, 2020*	Global	higher education (college and University)	Review	Thermal neutral sensation will occur at different indoor temperatures, between 19.5 and 23.3°C. This will vary by outdoor temperature and period of transition to classroom temperature. In one study, students' cognitive performance peaked at 23°C and declined by 48 percent at a higher temperature of 30°C.

Table 1. Continued

Exposure	Title Author *Journal, Year*	Country	Student population	Study type	Key finding
High temperature	**Temperature and Human Capital in India** Teevrat Garg, Maulik Jagnani, and Vis Taraz *Journal of the Association of Environmental and Resource Economists, 2020*	India	primary and secondary school	Observational	For each additional hot day (defined as a day above 29°C) in the year prior to the exam, learning is reduced by 0.003 standard deviations (in math) and 0.002 deviations (in reading)
High temperature	**The effects of summer heat on academic achievement: A cohort analysis** Hyunkuk Cho *Journal of Environmental Economics and Management, 2017*	Korea	high school (Korean college entrance exam)	Observational	For each hot day (defined as a day with a maximum temperature above 34 C) in the summer preceding the exam, learning in math and English was reduced by 0.0042 and 0.0064 standard deviations.
High temperature	**Weather and high-stakes exam performance: Evidence from student-level administrative data in Brazil** Xiaoxiao Li, Pankaj C. Patel *Economics Letters, 2021*	Brazil	high school (Brazil college entrance exam)	Observational	No strong effect of temperature on exam performance was observed, with a 1°C increase in dry bulb temperature improving z-scores by three-thousandths of a standard deviation.
High temperature	**Temperature, effort, and achievement: Evidence from a large-scale standardized exam in Brazil** Ana Paula Melo, Mizuhiro Suzuki *Working paper, 2021*	Brazil	high school (Brazil college entrance exam)	Observational	One standard deviation increase in temperature during the exam decreases the average exam score by 0.036 of a standard deviation.

Table 1. Continued

Exposure	Title Author *Journal, Year*	Country	Student population	Study type	Key finding
High temperature	**Temperature and Low-Stakes Cognitive Performance** Xin Zhang, Xi Chen, Xiaobo Zhang *Journal of the Association of Environmental and Resource Economists, 2024*	China	population older than 10 years	Observational	High temperature on test day (above 32°C on the test date relative to a day within 22°C–24°C) lowers math scores by 0.066 standard deviations.
High temperature	**Decreased humidity improves cognitive performance at extreme high indoor temperature** Xiaoyu Tian, Zhaosong Fang, Weiwei Liu *Indoor Air, 2020*	China	college students	Experimental	At constant relative humidity, increasing indoor temperature from 26°C to 39°C increased reported health symptoms of dry throat, dry skin and headaches, dizziness, difficulty in thinking and concentrating clearly, fatigue, and decreased well-being and mood. This also decreased accuracy on cognitive tests.
High temperature	**Investigation of students' short-term memory performance and thermal sensation with heart rate variability under different environments in summer** Yalong Yang, Lin Hu, Rui Zhang, Xulai Zhu, Mingyue Wang *Building and Environment, 2021*	China	university students	Experimental	No significant difference in short-term memory performance observed for changes in temperature and correlated color temperature.

Table 1. Continued

Exposure	Title Author *Journal, Year*	Country	Student population	Study type	Key finding
High temperature	**Effects of different classroom temperatures on cardiac autonomic control and cognitive performances in undergraduate students** F Barbic, M Minonzio, B Cairo, D Shiffer, A Dipasquale, L Cerina, A Vatteroni, V Urechie, P Verzeletti, F Badilini *Physiological Measurement, 2019*	Italy	university students	Experimental	Cognitive C-score scores were lower during day 2 (hotter day) in a two day experiment. Student's thermal comfort was lower during Day 2 compared to Day 1.
High temperature	**Effects of a cool classroom microclimate on cardiac autonomic control and cognitive performances in undergraduate students** Franca Barbic, Maura Minonzio, Beatrice Cairo, Dana Shiffer, Luca Cerina, Paolo Verzeletti, Fabio Badilini Martino Vaglio, Alberto Porta, Marco Santambrogio, Roberto Gatti, Stefano Rigo, Andrea Bisoglio, Raffaello Furlan *Science of the Total Environment, 2022*	Italy	university students	Experimental	Greater cognitive performance observed during the COOL trial was associated with a lower cardiac sympathetic and greater cardiac vagal modulation.

Table 1. Continued

Exposure	Title Author *Journal, Year*	Country	Student population	Study type	Key finding
High temperature	**Reducing classroom temperature in a tropical climate improved the thermal comfort and the performance of elementary school pupils** Jose Ali Porras-Salazar, David P. Wyon, Beatriz Piderit-Moreno, Sergio Contreras-Espinoza, Pawel Wargocki *Indoor Air, 2018*	Costa Rica	elementary school students	Experimental	An intervention that reduced classroom temperatures showed that the 11-year-old children had a significantly higher speed on the language and logical-thinking tasks at the lower temperature, while the less able pupils performed better on all tasks at the lower temperature. There were no significant effects on accuracy.
High temperature	**Climate warming causes declines in crop yields and lowers school attendance rates in Central Africa** Trevon L. Fuller, Paul R. Sesink Clee, Kevin Y. Njabo, Anthony Tróchez, Katy Morgan, Demetrio Bocuma Meñe, Nicola M. Anthony, Mary Katherine Gonder, Walter R. Allen, Rachid Hanna, Thomas B. Smith *Science of the Total Environment, 2018*	Cameroon	School-aged children (5–19)	Observational	Climate has decreased plantain yields in Cameroon which is associated with a decrease in school attendance.
High temperature	**Climate variability and educational attainment: Evidence from rural Ethiopia** Heather Randell, Clark Gray *Global Environmental Change, 2016*	Ethiopia	Children aged 12–16	Observational	Milder temperatures during all seasons and greater rainfall during the summer agricultural season in early life are associated with an increased likelihood of children completing any education.

Table 1. Continued

Exposure	Title Author *Journal, Year*	Country	Student population	Study type	Key finding
High temperature	**Effects of Classroom Ventilation Rate and Temperature on Students' Test Scores** Ulla Haverinen-Shaughnessy & Richard J. Shaughnessy *PloS one, 2015*	United States	Elementary school students	Observational	Each 1°C decrease in classroom temperature increased test scores by 12–13 points.
Cyclones, hurricanes, floods	**Integration of face-to-face and virtual classes improves test scores in Biology undergraduate courses on days with flooding in Brazil** Santana OA, Silva TP, Oliveira GS, Silva MM, Inacio ED, Encinas JI. *Acta Scientiarum. Education, 2013*	Brazil	Biology under-graduate	Observational	On flood days, student participation was lower, but have virtual classes attenuated these effects.
Cyclones, hurricanes, floods	**The impacts of natural disaster on student achievement: Evidence from severe floods in Thailand** Kawin Thamtanajit *The Journal of Developing Areas, 2020*	Thailand	Students grade 6–12	Observational	Floods had negative effects on test scores for students in grade 6 and 9, but not grade 12m except for social studies. Changes in test score from flooding ranged from 0.03 to 0.11 standard deviations, depending on the subject and level.
Cyclones, hurricanes, floods	**Medical Education in Post-Katrina New Orleans** **A Story of Survival and Renewal** N. Kevin Krane, Richard P. DiCarlo, Marc J. Kahn *JAMA, 2007*	United States	medical students	Descriptive	There are long term effect on Tulane University School of Medicine and Louisiana State University School of Medicine at New Orleans (LSU) following hurricane Katrina.

Table 1. Continued

Exposure	Title Author *Journal, Year*	Country	Student population	Study type	Key finding
Cyclones, hurricanes, floods	**The impact of extreme weather on student online learning participation** Ezekiel Adriel D. Lagmay & Maria Mercedes T. Rodrigo *Research and Practice in Technology Enhanced Learning, 2022*	Philippines	undergraduate and graduate students	Observational	Student online participation decreased by – 20 percent due to typhoons.
Cyclones, hurricanes, floods	**Academic and Student Affairs Issues Post Hurricane Katrina** Camille Jarrell, Raymonda Dennis, Marian Jackson & Cynthia A. Kenney *Community College Journal of Research and Practice, 2008*	United States	community and technical colleges	Descriptive	There were long-term effects on the educational system post-Katrina and there is a needs for crisis-management programs in college and university settings.
Cyclones, hurricanes, floods	**The storm after the storm: the long-term lingering impacts of hurricanes on schools** Cassandra R. Davis, Sarah R. Cannon, Sarah C. Fuller *Disaster Prevention and Management, 2021*	United States	school districts	Descriptive	There are challenges that prolong the impacts of disasters and impede recovery in schools. There is a need to identify the best ways to support schools, months to years after an event.

Table 1. Continued

Exposure	Title Author *Journal, Year*	Country	Student population	Study type	Key finding
Cyclones, hurricanes, floods	**Hidden disasters: Recurrent flooding impacts on educational continuity in the Philippines** Jake Rom D. Cadag, Marla Petal, Emmanuel Luna a, J.C. Gaillard, Lourdes Pambid, Genia V. Santos *International Journal of Disaster Risk Reduction, 2017*	Philippines	school communities (students, teachers + staff)	Descriptive	There are severe impacts of small scale floods to school communities, particularly for the most marginalized students. Approximately 7–12 days of school are lost due to small scale floods every year.
Cyclones, hurricanes, floods	**School hazard vulnerability and student learning** Clarissa C. David, Sheryl Lyn C. Monterola, Antonino Paguirigan Jr., Erika Fille T. Legara, Anjali B. Tarun, Rene C. Batac, Jeriesa P. Osorio *International Journal of Educational Research, 2018*	Philippines	elementary and secondary public school students	Observational	Provinces located near inland bodies of water are vulnerable to floods and those in the eastern side of the country are most vulnerable to typhoons. The repeated use of school structures as evacuation centers has negative impact on school performance.
Cyclones, hurricanes, floods	**School vulnerability to disaster: examination of school closure, demographic, and exposure factors in Hurricane Ike's wind swath** A.-M. Esnard, B. S. Lai, C. Wyczalkowski, N. Malmin & H. J. Shah *Natural Hazards, 2017*	United States	school districts	Observational	School districts located in coastal counties on Hurricane Ike's path have an increase in the number of school closure days.

Table 1. Continued

Exposure	Title Author *Journal, Year*	Country	Student population	Study type	Key finding
Cyclones, hurricanes, floods	**The impact of flood disasters on child education in Muzarabani District, Zimbabwe** Chipo Mudavanhu *Jàmbá: Journal of Disaster Risk Studies, 2014*	Zimbabwe	school children	Observational	Floods cause loss of learning hours, loss of qualified personnel, outbreaks of waterborne diseases, high absenteeism and low syllabus coverage leading to children's poor academic performance. Food insecurity, being withdrawn from school and sometimes forced into early marriages are also described as challenges faced by children.
Cyclones, hurricanes, floods	**The Effects Of 2010 Flood On Educational Institutions And Children Schooling In Khyber Pukhtoonkhwa: A Study Of Charsadda And Swat Districts** Saif-ur-rehman Saif Abbasi & Bilal Shaukat International Journal of Environment, Ecology, Family and Urban Studies (IJEEFUS), 2013	Pakistan	school infrastructure	Descriptive	Infrastructure along with furniture and fixture and office record of 23 schools in two districts were damaged. The institutions were closed for three and more than three months either due to damage caused by flood or using these institutions as shelter homes for flood victims.
Droughts	**The impact of drought on human capital in rural India** Kuhu Joshi *Environment and Development Economics, 2019*	India	Primary and secondary school	Observational	Droughts led to a decline of 4.14 percent in math scores and 2.67 percent in reading scores of affected children.

Table 1. Continued

Exposure	Title Author *Journal, Year*	Country	Student population	Study type	Key finding
Droughts	**Impact of a Severe Drought on Education: More Schooling but Less Learning** Ardyn Nordstrom, Christopher Cotton *SSRN, 2020*	Zimbabwe	Girls in primary school	Observational	A 4 percent decline in math scores was observed for affected girls in Zimbabwe but literacy scores were not affected. However, the probability that students advance in school increased likely due to lower opportunity costs to education
Droughts	**Drought of opportunities: Contemporaneous and long-term impacts of rainfall shocks on human capital** Manisha Shah, Bryce Millett Steinberg *Journal of Political Economy, 2017*	India	Primary school	Observational	Higher wages increase human capital investment in early life (in utero to age 2) but decrease human capital from age 5 to 16. When rainfall is higher, children switch out of school into productive work.
Droughts	**Rainfall shocks, cognitive development and educational attainment among adolescents in a drought-prone region in Kenya** Laura Nübler, Karen Austrian, John A. Maluccio, Jessie Pinchoff *Environment and Development Economics, 2021*	Kenya	Girls in primary school	Observational	Past rainfall shocks have substantial negative effects on the cognitive development and educational achievement of girls. The probability of correctly answering all four reading questions was reduced by 13.0 percentage points for girls with a rainfall shock at age 0, i.e., during the first year of life. The probability of ever having enrolled in school was reduced by 16.9 percentage points and of having enrolled by age 8 by 20.7 percentage points. Years of schooling completed was reduced by 0.8 grades.

Table 1. Continued

Exposure	Title Author *Journal, Year*	Country	Student population	Study type	Key finding
Droughts	**How Do Early-Life Shocks Interact with Subsequent Human Capital Investments? Evidence from Administrative Data** Valentina Duque, Maria Rosales-Rueda, Fabio Sanchez *Working paper, 2019*	Colombia	High school exam	Observational	Children exposed to 8 months of “normal” weather conditions in utero and early childhood experiences a 5.0 percent increase in the probability of not dropping out of school and a 0.05 SD increase in exam scores.
Droughts	**Impact of weather shocks on educational outcomes in the municipalities of Colombia** Paola Palacios, Libardo Rojas-Velásquez International *Journal of Educational Development, 2023*	Colombia	middle and high school	Observational	Rainfall shocks reduce math scores by 3.95 and reading scores by 4.24.
Wildfire Smoke	**Lower test scores from wildfire smoke exposure** Jeff Wen, Marshall Burke *Nature Sustainability, 2022*	United States	grades 3–8	Observational	Relative to a school year with no smoke, average cumulative smoke-attributable PM2.5 (surface particulate matter $< 2.5\,\mu g\,m-3$) exposure during the school year ($\sim 35\,\mu g\,m-3$) reduces test scores by $\sim$0.15 percent of a standard deviation.

Table 1. Continued

Exposure	Title Author *Journal, Year*	Country	Student population	Study type	Key finding
Wildfire Smoke	**Do Wildfires Harm Student Learning?** Ge Wu *Haslam College of Business Working Paper, University of Tennessee, Knoxville, 2022*	United States	grades 3–8	Observational	Wildfire smoke plumes significantly lowers test scores- a 10-day increase in smoke exposure within 1 year prior to tests decreases students' ELA test scores by 0.003 standard deviations and math scores by 0.004 standard deviations.
Wildfire Smoke	**Impact of short school closures (1–5 days) on overall academic performance of schools in California** Rebecca K. Miller & Iris Hui *Scientific reports, 2022*	United States	schools	Observational	Wildfires are responsible for the majority of school closures in California. Wildfires generate significant negative impacts on academic performance among younger students.
all	**Climate Change and Schools: Implications for Children's Health and Safety** Stephanie Chalupka and Laura Anderko *Creative Nursing, 2019*	United States	schools	Descriptive	Flooding, hurricanes, tornadoes, and wildfires are challenging communities to re-evaluate whether their schools provide a safe, healthy environment.

Table 1. Continued

Exposure	Title Author *Journal, Year*	Country	Student population	Study type	Key finding
all	**Assessment of vulnerability and resilience of school education to climate-induced hazards: a review** Anushree Pal,Takuji W. Tsusaka,Thi Phuoc Lai Nguyen &Mokbul Morshed Ahmad *Development Studies Research, 2023*	global	schools	Review	Damaged infrastructure causes school closures for extended periods, which can produce discontinuity in education. There is a need for policies on how to implement Comprehensive School Safety Framework and build schools resilience.
all	**Climate Changes Affect Human Capital** Germán Caruso, Inés de Marcos & Ilan Noy *Economics of Disaster and Climate Change* *2024*	Conceptual framework	All ages	Review	From direct effects on health, nutrition, and wellbeing, and indirect effects on economic systems, markets, and through damage to infrastructure, climate change impacts human capital across the life cycle.

Source: Authors' analysis based on review of selected literature.
Note: Included impacts are not exhaustive.

Elevated temperature in classroom environments has acute effects on the physiology of students, increasing heart rates and affecting perception and spatial orientation (Brink et al. 2021). These physiological responses have been linked to reduced accuracy and speed in cognitive tests, translating into diminished learning outcomes (Porras-Salazar et al. 2018; Barbic et al. 2019; Tian et al. 2021; Barbic et al. 2022; Vu 2022).

Cumulative exposure to higher temperatures or "hot" days in the months/years prior to an exam can also impact learning. Rather than evaluating the acute effects of heat, these studies consider the medium or long-term negative effects of exposure to extreme heat on school days (Cho 2017; Garg et al. 2020; Park et al. 2020). In the medium or long-term, heat not only affects learning, but can also trigger lower attendance and higher dropouts.

Extreme heat will disproportionally affect the poorest regions. Warmer and lower resource settings are facing higher exposures to extreme heat conditions and as a result experiencing the greatest burden on education outcomes. Each hot day can also have different effects on populations across and within countries, as the socioeconomic conditions and resources of schools and students will affect resilience to these stressors. For example, hot days may not have the same effect on students attending a school with air conditioning as on students in a school with no electricity and improper ventilation.

Impacts on Learning

Exposure to high temperatures has a negative impact on learning outcomes. A number of studies have evaluated how exposure to high temperatures in the year(s) prior to standardized tests affect scores. In Brazil, an increase of 1°C during the two years prior to a national assessment translates into ~0.03SD losses in test scores (Schady et al. 2024). Park et al. (2020) found that learning is reduced by 1 percent for every 1°F increase in temperature in the school years preceding exams, using scores from the Preliminary Scholastic Aptitude Test (PSAT), a practice college entrance exam in the United States (Park et al. 2020). Roach and Whitney (2022) also evaluated the effects of average maximum temperature on English/Language Arts and Math test scores from the Stanford Educational Data Archive (SEDA) for students in third grade through eighth grade across the United States (Roach and Whitney 2022). They find that a 1°F increase in average maximum temperature leads to up to a 4.71 percent reduction in mean test scores (Roach and Whitney 2022).

Larger effects are observed when considering the effects of extreme heat days on learning. Several studies have shown that for every additional day of extreme heat, at least one day of learning is lost (Cho 2017; Garg et al. 2020; Park et al. 2020; Park et al. 2021; Roach and Whitney 2022). Across 58 countries participating in the Programme for International Student Assessment (PISA) between 2000 and 2015, Park et al. (2021) found that exam scores decreased by 0.18 percent of a standard deviation for every additional hot day (above 26.7 °C/80 °F) in the three years prior to the exam, equivalent to 1.08 days of learning lost.[3] This was driven by high temperatures on school days (on school days, 0.22 percent change equivalent to 1.33 days lost) and affected primarily poorer countries. Besides the global analysis, only a few studies have considered the effects of cumulative exposure to high temperatures on academic achievement outside of the United States. Cho (2017) used city-level temperature data to evaluate the effects of hot days during the summer on test scores for the Korean college entrance exam, which occurs in November (Cho 2017). The study found that math and English scores decreased by 0.0042 (equivalent to 2.52 days of learning lost) and 0.0064 (equivalent to 3.84 days of learning lost) standard deviations, respectively, with every additional day with a maximum daily temperature over 34°C relative to a day in the 28–30°C in the summer months. Garg et al. (2020) used survey data on educational achievement in primary school children in India to evaluate the effect of the number of hot days in the calendar year prior to the year of the test on scores, finding that math and reading test performance was reduced by 0.03 and 0.02 standard deviations, respectively, equivalent to 1.2 to 1.8 days of learning lost, for each additional day with average daily temperature more than 29°C relative to 15°–17°C (Garg et al. 2020).

Extreme heat is also found to hinder performance on the day of the exam. Across six studies considering temperature on the exam day, the effect of a 1°C increase in temperature during the exam lowered test scores up to 2.91 percent of a standard deviation (Zivin et al. 2020; Melo and Suzuki 2021; Li and Patel 2021; Park 2022; Vu 2022; Zhang et al. 2024). This has consequences on student achievement and academics, which could be particularly problematic for high-stakes exams where one's future stands on the line. Zivin et al. (2020) studied how hot weather affects students' performance in China's National College Entrance Examination (NCEE). They discovered that for every 1°C rise in temperature during the two-day exam period, test scores dropped by 2.91 percent of a standard deviation (Zivin et al. 2020). Melo and Suzuki (2021) conducted a similar analysis in Brazil, considering impacts of daily municipality-level temperature estimates on scores on the National High School Evaluation Exam (ENEM), which is used for students' admission to universities. They find that a one standard deviation increase in temperature (equivalent to 3.679°C) during the exam decreases scores by 0.036 of a standard deviation (Melo and Suzuki 2021). Vu (2022) also studied effects of average temperature on test days on scores in the Vietnamese national university and college entrance examinations in 2009 and found that a 1°F increase on the test day was associated with an approximate 0.006 SD decrease in standardized test scores (Vu 2022). Students in rural areas and women were found to be particularly vulnerable to these effects (Vu 2022). Park (2022)evaluated effects of exam-day ambient temperature on high stakes exams in New York city and found a 13 percent of a standard deviation lower exam score when the temperature was 90°F as compared to 75°F (Park 2022). A study in China found that temperatures above 32°C on the test date, relative to days within 22°C–24°C, decrease math scores by 0.066 standard deviations, which they translate to be equivalent to losing 0.23 years of education (Zhang et al. 2024).

The human body's reaction to heat stress is at the core of these impacts. A body's physiological response to heat stress can produce vasodilation, an increased blood flow to the skin, putting increased strain on the heart which affects the body's thermoregulatory capacity (Ebi et al. 2021). Exposure to higher temperatures can also produce changes in heart rate and respiratory rates. A study on emergency department visits of children in the United Kingdom found an increase of approximately 10 beats per minute for every degree Celsius increase in body temperature (Davis et al. 2021). The effects of high temperature on respiratory rates are less clear with some studies finding no clinically meaningful effects on respiratory rates (Heal et al. 2022) and others showing an increase in respiratory rate of up to 2 breaths per minute per degree Celsius increase in body temperature (Davies and Maconochie 2009). These physiological responses to high temperatures, as well as the discomfort and distraction of being in a hot environment, can affect students' learning and academic achievement. Raising both skin and core temperature can increase strain on the cardiovascular system, producing faster reaction times and decreased accuracy in cognitive tests (Simmons et al. 2008). A systematic review on ambient air temperature and cognitive performance finds that hot temperatures decrease performance, leading to a 5 percent decrease in accuracy and 3 percent decrease in speed in cognitive tasks (Yeganeh et al. 2018).

Research studying the indoor built environment and human comfort demonstrates the association between indoor temperature and thermal comfort. This evidence uses physiological indicators such as heart rate, blood pressure, heart activity, brain activity, skin conductivity and oxygen saturation to evaluate these effects. An experimental study considering 60 different environmental conditions with varying combinations of air temperature, relative humidity, and air speed found that air temperature had the strongest effect on heart rate variability (HRV), which is associated with thermal comfort (Liu et al. 2008; Zhu et al. 2018; Yang et al. 2021). A study evaluating cognitive performance under hot environmental conditions found that results for cognitive tasks decreased as heart rate variability increases (Zhu et al. 2018). A review of the effects of acoustic, thermal, and illumination conditionson human perception and performance, including both experimental studies and field experiments in indoor environments, identified that temperature level considered satisfactory for human comfort is between 21°C and 27°C (Yang and Moon 2019; Yang et al. 2021).

Experimental studies have explored the effect of classroom temperature on student cognitive outcomes, measured by memory, speed, and accuracy in cognitive tests. Across five out of seven experimental studies considering the effect of classroom temperature on cognitive performance, for every 1°C increase in classroom temperature, student performance decreases by an estimated range of 2 percent to 12 percent (Porras-Salazar et al. 2018; Barbic et al. 2019; Wargocki et al. 2019;

Brink et al. 2021; Barbic et al. 2022).[4] A review and meta-analysis compared effects of temperature on schoolwork and office work and found that the optimal temperature for schoolwork is lower and that effects are greater in a school setting. They suggest that children may have different thermal perceptions and find that children prefer classroom temperatures 2–3°C lower than adults in office spaces (Wargocki et al. 2019). Barbic et al. (2022) found that even under minimal thermal discomfort, university students in a cool (18.4 ± 0.4°C) classroom had a lower heart rate variability than students in a neutral (21.5 ± 0.8°C) temperature classroom, which also produced improvements in short-term memory, verbal ability, and overall cognitive scores (Barbic et al. 2022). A study by some of the same authors also showed that lower classroom temperatures in a two day-study (Day 1: 22.4°C ± 0.1°C; Day 2: 26.2°C ± 0.1°C) showed decreased thermal discomfort and a shift in sympathetic predominance and higher short-term memory, verbal ability, and overall cognitive scores (Barbic et al. 2019). In China, higher classroom temperatures increased reported health symptoms of dry throat, dry skin, headaches, dizziness, difficulty in thinking and concentrating clearly, fatigue, and decreased well-being and mood (Tian et al. 2021).

Most concerningly, because rising temperatures is a slow and gradual process, even slight increases in heat have a significant cumulative impact. A forthcoming study from Brazil delves into the connection between heat and learning, providing valuable insights (Schady et al. 2024). The study finds that in the hottest 10 percent of municipalities, maximum daily temperatures experienced by schools rose more quickly (at a rate of about 0.6 degrees Celsius per decade) than in the other 90 percent. In these municipalities, which are also the most disadvantaged, students lost about 1 percent of learning per year due to rising temperatures. If one assumes that learning is entirely cumulative with each year's learning building on those before, and that each year 1 percent of learning is lost, by the time a student completes grade 12, that student will have lost about 1.5 years of learning. If by contrast, one assumes a more realistic mix of learning being cumulative in the early years and more independent in the later years, by the time a student completes grade 12, that student will have lost about 0.66 years of learning. In essence, the study finds that a child who enters 1st grade today in a municipality already experiencing high temperatures will lose between 0.66 and 1.5 years of learning by the time they graduate from 12th grade. Given the assumptions, the estimate of 1.5 years of learning lost is the unlikely upper bound of possible impacts, while 0.66 is a more reasonable estimate that signals the magnitud of the problem.

The combination of these strands of research offers an understanding of the complex relationship between heat and learning. Studies that look at increases in the average temperature in the year(s) prior to an exam find relatively small impacts while studies that look at the incidence of extreme heat on school days find larger impacts. Experimental studies add texture to these findings. They suggest that it is surpassing a temperature threshold that makes learning more difficult and results in learning losses, rather than a linear relationship between temperature and learning. This implies that there are temperature levels at which it is just difficult to focus, so it is only when those levels are reached that learning is inhibited. Increasing temperature by 1 degree may not have adverse effects depending on the context, but if that extra degree pushes the temperature to a level that makes learning difficult, then learning losses happen in the absence of any adaptation measure. While the impact of individual hot days may be perceived by some to be small, they compound over time resulting in significant learning losses.

Impacts on Enrollment, Dropouts, and Long-Term Outcomes

Decreased levels of learning lead to higher dropout rates. When children are exposed to extreme heat, they learn less. This has implications that go beyond learning. Several studies have shown that lower student performance is linked with a higher probability of dropping out, and vice versa. In Senegal, a one standard deviation improvement in a grade 2 test score is associated with a 22-percentage point increase in the probability of completing grade 6 (Glick and Sahn 2010). Similarly, when a test score is one standard deviation higher, students in Ethiopia, India, Peru, and Vietnam were found to have 50 percent lower odds of dropping out between the ages of 8 and 12 (Kaffenberger 2021). In contrast, qualitative analysis indicates a direct relationship between low learning and dropout, with children and parents choosing to discontinue school when they realize how little is being learned (Kaffenberger 2021). Lower achievement on academic scores can increase the risk of dropping out by increasing the perceived opportunity cost of sending children to school. In Kenya, among students who dropped out early, falling behind peers and being unable to process the content being taught was cited as the most common reasons for dropping out (Pritchett and Beatty 2015; Zuilkowski et al. 2016).

A few studies evaluate how high temperatures will impact long-term education outcomes and human capital production and discuss the potential long-term effects. Park (2022) shows that high temperatures on exam day decreased the likelihood of passing a subject as well as reduced graduation rates for high school students in New York City (Park 2022). Garg et al. (2020) discuss that longer-run temperature can affect agricultural income and damage livelihoods, which was found to reduce school attendance (Garg et al. 2020). A study in Cameroon finds a reduction in plantain yields due to climate change which was found to decrease parental investment in education (Fuller et al. 2018). The study predicts that plantain yields will decrease by 39 percent by 2080 due to climate change, which will be associated with a 51 percent reduction in average years of schooling compared to 1991 baseline measures (Fuller et al. 2018).

There are many reasons for which dropouts may be a consequence of exposure to high temperatures. In the short term, a hot day could change behavioral patterns in student absenteeism due to potential disturbances in transportation or higher discomfort when attending school, particularly for schools that do not have access to air conditioning or good air flow. This has been shown for adult labor supply, which decreases with high temperature (Zivin and Shrader 2016). Interestingly, one study even showed study subjects dropping out of the experiment due to thermal discomfort at temperatures above 39°C (Tian et al. 2021). In the medium term, exposure to high temperatures seems to be associated with lower school attainment. A study in Ethiopia finds that a child who experiences above average spring temperatures (0.5 standard deviations above long-term mean) has 21 percent lower odds of completing one grade of school (Randell and Gray 2019).

Tropical Cyclones, Floods, and Education Outcomes

Tropical cyclones and flooding can have impacts on education through their effects on learning, attendance, and long-term academic achievement. Learning can be impacted through school closures that prevent students from going to school. Even when schools are not closed, issues with transportation to and from the school can hinder attendance and participation, also affecting learning. Extended closures due to infrastructure damage or the use of schools as evacuation centers have adverse effects on schooling continuity. Lastly, tropical cyclones and floods can also have lasting effects on education through decreased enrollment, increased dropouts, and an overall negative effect on long-term educational achievement.

Impacts on Learning

Tropical cyclones and storms often close schools, halting all learning. Effects of these storms can include flash floods, landslides, and tidal surges which can have detrimental impacts on schools and lead to closures. For example, storm Ana in Mozambique destroyed almost 800 schools in early 2022, all of which were unable to open following the storm (BBC 2022). Another storm, Cyclone Freddy, which affected Malawi, Mozambique, Madagascar, South Africa, and Zimbabwe in March 2023, also affected schools and student attendance; about half a million students in Malawi, or 5 percent of students across the county, were not able to attend school due to school closures in the affected areas (Mugo 2023). Another tropical storm in the northern Philippines in August 2022 also led to school closures in the capital (AP 2023). Classes are automatically suspended during a typhoon in the Philippines, and it can take over a week to clean the classrooms; this was found to happen at least twice a month in some regions during the rainy season (Cadag et al. 2017). Although school closures are sometimes necessary, they will have consequences on student learning and achievement. There is strong evidence that school closures produce learning losses (Schady et al. 2023). During the first years of the COVID-19 pandemic (March 2020–2022), each month of closures translated to a month of learning losses (Sabarwal et al. 2023).

We can extrapolate from the drastic impacts of school closures related to COVID-19 that storm and cyclone-driven school closures will also have severe consequences on learning.

The vulnerability of school infrastructure increases the risk of extended school closures. The damage extreme weather events cause to school infrastructure will largely determine both the length of the school closure as well as the learning that will be impacted. Higher levels of damage mean that schools will take longer to guarantee a safe environment before students can return. In the case of complete school destruction, the provision of education services will take even longer. The extent of the damage ultimately depends on the school's resilience, and unfortunately a significant number of schools are unprepared to cope with extreme weather and climate shocks. For example, the World Bank's Pacific Safer Schools Program found that between 50 and 90 percent of 6,000 school buildings across Samoa, Tonga, and Vanuatu may not withstand a strong cyclone or earthquake (World Bank 2022a). Recent climate shocks highlight similar vulnerabilities in other regions. In Haiti, physical damage to the education sector from natural disasters has damaged one in four schools across the country. The low level of resilience in school infrastructure globally amplifies damages, thereby extending school closures that halt learning.

The use of school facilities as evacuation centers can also prolong school closures, affecting education and learning. Schools are often used as such following storms and floods as shown in recent emergencies in the Philippines, Haiti, Libya, Pakistan, and Japan (UNICEF 2016, 2023;Cadag et al. 2017; Perry et al. 2023). Schools used as evacuation centers for extended periods not only keep children out of school but can also produce long-term damage to school facilities when improperly managed. In Haiti, Hurricane Mathews led to over 100,000 children being out of school due to the facilities being damaged or used as temporary shelters (UNICEF 2016). This was the case even months after the hurricane. In Pakistan, 92 percent of households affected by flooding in 2022 were still uncertain six months later of when local schools would re-open (Perry et al. 2023). The use of schools as evacuation centers can compromise the continuity of schooling accessibility and can have detrimental impacts on enrollment and long-term educational achievement. A study in the Philippines investigated links between school hazards (floods, earthquakes, and typhoons) and found that the repeated use of school structures for evacuations during hazards had adverse impacts on the academic performance of students (David et al. 2018). After flooding, students also report the destruction of learning materials and the use of schools as evacuation centers as challenges to the learning environment (Cadag et al. 2017). A study in flood-affected regions of Pakistan found that institutions remained closed for over three months due to infrastructure damage or the use of schools as shelter homes for flood victims (Saif-Ur-Rehman and Shaukat 2013).

Even when schools are not closed, tropical cyclones, hurricanes, and typhoons can reduce attendance and participation. There are more absences during the rainy season even when classes are not suspended, often due to challenges in transportation and particularly for more vulnerable students. A study in metropolitan areas of Brazil that evaluated the use of face-to-face and virtual classes for Biology undergraduate students in areas affected by floods found that on flood days, students spent more time travelling from home to the university (2.54h $\pm$ 0.52 on flood days vs. 1.24h $\pm$ 0.83 on non-flood days) (Santana et al. 2013). There was also a difference in attendance, whereby the percentage of students present for face-to-face classes decreased from 77 percent on days without flooding to 27 percent on days with flooding (Santana et al. 2013). This influenced test scores, with those who had only face-to-face classes showing approximately 33 percent lower test scores on average, but no difference was observed when students had access to both face-to-face and virtual learning options. This highlights the potential use of online learning to limit the impacts of flooding on learning in the Brazilian context (Santana et al. 2013).

There is specific evidence that the effects of floods and storms adversely affect learning. Several studies have considered how flooding can decrease test scores and the participation of affected students. A study on climate shocks in Colombia, in which the majority of shocks were floods and landslides, showed negative impacts on test scores in a national standardized exam for high school students (Valencia Amaya 2020). Qualitative research in Zimbabwe indicated that floods were associated with a loss in learning hours (Mudavanhu 2014). A study from Thailand evaluated the effect of the 2011 floods on test scores and found flooding to be associated with decreases in test scores for most grade levels and subject areas (Thamtanajit 2020). During Hurricane Katrina in New Orleans, communication, issues with housing, and emotional and financial impacts were important effects of the hurricane for medical students at Tulane University School of Medicine and Louisiana State University School of Medicine (Krane et al. 2007). Typhoons in the Philippines in October and November 2020, concurrent to COVID-19, decreased overall student online participation but participation in assignments and quizzes was not affected (Lagmay and Rodrigo 2022). Overall, increasing floods and typhoons will adversely affect student learning and participation, impacting student achievement. This can also have long-term effects on schooling and educational outcomes.

Impacts on Enrollment, Dropouts, and Long-Term Outcomes

Storms such as floods and hurricanes can have detrimental consequences on educational systems that can increase dropouts. Mudavanhu (2014) conducted research in Zimbabwe and found that floods led to a loss of qualified educators, outbreaks of waterborne diseases, higher absenteeism, and lower coverage of learning material, which had long-term effects on education (Mudavanhu 2014). Absenteeism was highest during the rainy season and attendance was only 50 percent during these months (January–March). Over 17 percent of children in this region dropped out of school due to socioeconomic and behavioral factors that were likely exacerbated by floods (Mudavanhu 2014).

After school closures, some students will not return, further increasing dropout rates. School closures also increase dropouts as many students never return to school when it reopens. For example, in Chile, school closures increased the probability of students dropping out of high school by 49–68 percent (Grau et al. 2018). Evidence from the COVID-19 pandemic found that school closures were associated with up to 35 percent dropouts; this was higher among students with lower socioeconomic status, potentially exacerbating learning inequalities (Moscoviz and Evans 2022). Following COVID-19 school closures, in Ethiopia and Pakistan, school enrollment among children 6–14 dropped by 4 percentage points and 6 percentage points respectively, once schools re-opened post-COVID (Schady et al. 2023). Declines were much larger for students from lower socioeconomic backgrounds. School closures driven by storms/typhoons will show similar effects.

For individuals, reduced education attainment will translate into lower earnings and productivity. Dropouts are associated with lower school attainment and will have long-term consequences on income and human capital (McCaul et al. 1992). There is strong evidence that school attainment is linked with higher earnings, with estimates suggesting a return of 9–10 percent for each additional year of schooling (Psacharopoulos and Patrinos 2018). The returns are higher specifically among the groups that will be most impacted by climate change—poorer countries and girls. This implies that as climate shocks reduce education attainment, future earnings will also suffer, particularly in poorer countries and among girls. It has been shown that students in grades 1–12 affected by school closures will earn 3 percent less over their lifetimes (Hanushek and Woessmann 2020).

It will be important to continue understanding and tracking the long-term effects of hydrometeorological disasters such as floods, hurricanes, and cyclones on education outcomes in the context of climate change. Projections show that Southeast Asia, India, Eastern Africa, and the Andes will be regions particularly affected by flood risk in the context of climate change and should be prioritized in preventative actions to limit destruction (Hirabayashi et al. 2013).

Droughts and Education Outcomes

Although fewer studies have considered the effects of droughts on learning, enrollment, and attendance, there is some evidence that rainfall shocks and droughts can have an impact on cognitive development and education achievement. There are also long-term impacts of droughts on the continuity of education. The evidence of droughts and rainfall shocks on education outcomes shows that they adversely affect learning as well as school attainment. However, negative rainfall shocks are associated with increased schooling in some contexts. It will be important to better prepare for the consequences of drought-impacted regions on education outcomes.

Impacts on Learning

Droughts adversely affect learning. A study in the rural areas of the state of Maharashtra in India found that drought was associated with a 4.14 percent decrease in math scores and 2.67 percent decrease in reading scores for primary and secondary school children (Joshi 2019). A study of the droughts that occurred from October 2015 to April 2016 in Southern Africa found a 4 percent decline in math scores for affected girls in Zimbabwe but literacy scores were not affected (Nordstrom and Cotton 2020). Leadership attitudes were also found to be lower for affected students (Nordstrom and Cotton 2020). Shah and Steinberg (2017) found that children in India had a 0.012–0.04 point higher score in math and reading for each additional year with exposure to rainfall early in life in contrast to years with drought and this also increased the probability of being on track with schooling (Shah and Steinberg 2017). Although the evidence base for the effects of drought on learning is not extensive, existing studies have found exposure to droughts to negatively impact learning outcomes.

Impacts on Enrollment, Dropouts, and Long-Term Outcomes

There are mixed results regarding the effect of droughts on enrollment and long-term educational outcomes. Drought-induced water scarcity can negatively affect school attendance and dropouts. A number of studies show a decreased investment in schooling and enrollment following a drought. The study by Nübler et al. (2021)in pastoralist Kenya found that long-term effects of rainfall shocks led to strain on household resources and lower expenditure on schooling, even 10 years after the shock (Nübler et al. 2021). In Yemen, climate change is making rainfall scarcer and less reliable, prompting many children in rural communities to drop out of school to collect limited drinking water (World Bank 2022b). Rainfall shocks during early childhood and schooling-age also lowered the probability that the child enrolled in school, and reduced years of schooling by 0.8 (Nübler et al. 2021). Indonesian girls living in areas enriched by rain during childhood are not only healthier and taller but also attain more schooling (Almond et al. 2010).

In some contexts, droughts have been found to show a positive effect on attendance. Children are taken out of school to productive work when there is more need; therefore, when a drought occurs the opportunity cost of sending children to school decreases (Shah and Steinberg 2017; Nordstrom and Cotton 2020). In Zimbabwe, compared to those that were unaffected, girls affected by droughts were 2.8 percent more likely to be enrolled in school one year following the drought and 7.9 percent less likely to repeat a grade (Nordstrom and Cotton 2020). Shah and Steinberg (2017) also found that children in India who are affected by droughts are 0.3 percent less likely to drop out the year following the drought and 4 percent more likely to have attended school the previous week (Shah and Steinberg 2017). In Ethiopia, exposure to summer droughts in early childhood decreases odds of completing schooling by 16 percent (Randell and Gray 2019). A study in Colombia also finds that deficit rainfall shocks decrease dropouts and academic performance (Palacios and Rojas-Velásquez 2023). The change in demand for work in agriculture or the household can decrease the cost of sending children to school, having a positive effect on long-term education.

Wildfires and Education Outcomes

Wildfires can have impacts on populations and communities affected by the fire itself through displacement. They can also produce high levels of smoke, affecting much larger areas and populations by spreading far beyond the wildfire perimeters. Smoke from wildfires consists of high levels of fine particulate matter, a pollutant that has detrimental impacts on education outcomes and can also produce school closures in some regions. Recent evidence has also shown air pollution to be associated with lower learning and academic achievement, and several studies have evaluated the specific effect of wildfire smoke.

Impacts on Learning

Wildfires can cause damage to schools and lead to closures which can have important impacts on learning outcomes. For example, two school buildings collapsed and one was severely damaged during the 2018 Camp Fire in California (Schulze et al. 2020). School closures can also be a response measure from governments and school officials to protect students from wildfire smoke. Wildfire smoke is a form of air pollution, and includes high concentrations of fine particulate matter ($PM_{2.5}$), which has known adverse impacts on human health (Reid et al. 2016; Aguilera et al. 2021). School closures can be used to limit student exposure to unhealthy air during transportation to and from school and during the school day. In California, over 31 million student-days of wildfire smoke exposure occurred in the 2020–2021 school year (Velásquez et al. 2023). Wildfires and their smoke have been responsible for the majority of short-term school (1–5 days) closures in California which were shown to adversely affect academic performance for younger students, although older students were unaffected (Miller and Hui 2022). During major wildfires in California in 2020, 18 percent of the state's public school enrollment stayed home due to school closures (Cano 2020).

Air pollution adversely affects student learning. There are numerous studies that quantify the impacts of fine particulate matter ($PM_{2.5}$) on academic achievement by comparing changes in exposure to ambient air pollution and test scores in different regions around the world including Italy (Bernardi and Keivabu 2023), the United States

(Gilraine and Zheng 2022), the Islamic Republic of Iran (Amanzadeh et al. 2020), Brazil (Carneiro et al. 2021), Israel (Lavy et al. 2014), Chile (Miller and Vela 2013), China (Chen et al. 2017; Zhang et al. 2018), and India (Balakrishnan and Tsaneva 2021). The majority of these studies observe lower test scores for students with higher exposure to $PM_{2.5}$, which is a particularly harmful air pollutant due to its small size and ability to be inhaled deeply into the lung alveoli and even bloodstream. A review of the effects of traffic-related air pollution showed that 9 out of 10 studies found poorer academic performance in children and adolescents who were exposed to higher levels of traffic-related air pollution, although the quality of evidence was low (Stenson et al. 2021).

There is also evidence that wildfire smoke-specific air pollution impacts student achievement. Wildfire-specific $PM_{2.5}$ is more harmful to health than $PM_{2.5}$ from other sources and usually produces exposure at very high concentrations, therefore it is important to evaluate its specific effects (Aguilera et al. 2021). Wen and Burke (2022) used data from standardized test scores in the United States and satellite data to identify wildfire smoke and found that exposure to $PM_{2.5}$ from wildfire smoke reduces test scores by $\sim$0.15 percent of a standard deviation (Wen and Burke 2022). This effect is consistent across school subjects and has a higher effect on younger students (Wen and Burke 2022). Wu (2022) conducted a similar analysis and found that exposure to 10 additional wildfire smoke days was associated with a 0.003 standard deviation reduction in English and 0.004 standard deviation reduction in math scores (Wu 2022). Higher income in the United States has been shown to be much more likely to be able to leave the county during a smoke event, while more disadvantaged populations may not be able to as easily take measures to avoid exposure (Holloway and Rubin 2022).

Impacts on Enrollment, Dropouts, and Long-Term Outcomes

A few studies have evaluated the long-term outcomes of wildfire smoke exposure and observed substantial educational and economic impacts. Cheng et al. (2023) showed that one standard deviation increase in $PM_{2.5}$ exposure decreased parental spending in children's education by up to 44.6 percent (Cheng et al. 2023). Wen and Burke (2022) showed that the effects of wildfire smoke on test scores in one year, 2016, had long-term impacts and reduced future earnings of affected populations in the United States by \$1.7 billion, which burdened primarily disadvantaged populations (Wen and Burke 2022). School closures from wildfires and wildfire smoke can affect attendance and enrollment and have effects on children's educational success (Miller and Hui 2022). These studies highlight the need to continue to study these impacts to understand the full extent of how wildfire smoke impacts students and schooling in the long term.

Indirect Effects of Extreme Weather Events on Education Outcomes

Extreme weather events can affect the health, well-being, and social and economic environment of students and children, which will also adversely impact their educational outcomes. Climate extremes have effects on agricultural income and disease prevalence, produce food insecurity and nutrition-related effects, exacerbate mental health conditions, increase infectious diseases, and decrease sleep quality. They can cause harm across the life cycle, starting in utero, which can impact important determinants of success in education systems and potentially influence the long-term achievement of students. Extreme weather can also drive migration, conflict, and displacement, which can hinder students' school attendance and academic success.

Exposure to climate extremes impacts agriculture, food security, and income which have adverse effects on learning and schooling. Children in developing countries are particularly vulnerable to nutrient deprivation, infectious diseases, and unsafe environments—30 percent of children under 5 in developing countries are physically stunted, typically due to chronic malnutrition (Black et al. 2017). Extreme weather can affect livelihoods, loss of food availability, and even famine (Stanke et al. 2013; Algur et al. 2021). Climate extremes will increase food insecurity, particularly in vulnerable regions. It is estimated that up to 170 million additional people will be at risk of hunger by 2080 due to climate change (Schmidhuber and Tubiello 2007). Poor nutrition and health will have adverse effects on student learning and achievement. In India, agricultural income is an important driver of the effect of heat on academic achievement; impacts are stronger during the growing season and for districts without heat-resistant crops (Garg et al. 2020).

Income shocks and household coping mechanisms also jeopardize school enrollment. In the Republic of Korea, Cho (2017) suggests that the observed effect of hot summer days in decreasing Korean college exam scores is related to a decrease in time to study due to changes in summer job availability or parental income (Cho 2017). In Kenya, families that experienced historical rainfall shocks had about 10 percent less livestock and were less likely to have a metal roof or access to a latrine. This can produce strain on household resources and can lead to lower expenditure on schooling, even 10 years after a shock (Nübler et al. 2021). There are also social responses to cope with these stressors when families are particularly affected by economic strain due to climate. In Bangladesh, exposure to cyclones, floods, and droughts increases child marriages as families use bride payments as a coping mechanism for financial hardship (Asadullah et al. 2021). Taking girls out of the classroom to be married early will have drastic implications for their education. The economic strain of climate shocks on households negatively impact learning and access to school. Droughts can influence the likelihood of parents sending their kids to school, and lower teacher attendance due to decreases in wages, which are all potential mechanisms in affecting schooling (Shah and Steinberg 2017). There are actions that families may take in response to the economic strain caused by extreme weather events that will be highly impactful for student's well-being and education.

Exposure to extreme weather events has also been shown to impact mental health symptoms and conditions, which adversely affects academic achievement. Heat stress can produce mood disorders, anxiety, and other mental health conditions (Berry et al. 2010; Cianconi et al. 2020). A literature review on the associations between temperature and mental health outcomes also shows a higher risk of suicide from heat across studies and a higher risk of hospital admissions and emergency department visits for mental health (Thompson et al. 2018). Droughts can increase stress and are associated with increased suicides for farmers (Padhy et al. 2015). A study with 94 ninth grade ethnic minority students exposed to Hurricane Katrina found that the majority of students (69 percent) had mild-to-severe symptoms of post-traumatic stress disorder (Weems et al. 2009). Children and adolescents who experienced a wildfire disaster also have a higher risk of mental health symptoms, including depression and posttraumatic stress disorder (Brown et al. 2021; Ritchie et al. 2021), lower perceived quality of life, and lower self-esteem (Brown et al. 2019). A study evaluating the mental health of college students after the Fort McMurray wildfires showed that the prevalence of posttraumatic stress disorder in the study population increased by 11.0 percent after the wildfire (Ritchie et al. 2021). Another study that surveyed students in grades 7-to-12 for 3.5 years following the Fort McMurray wildfires showed that mental health symptoms worsened with time following the disaster and certain groups such as females, older students, and those with a minority gender identity were particularly susceptible (Brown et al. 2021). Climate anxiety can also be an important stressor for youth (Crandon et al. 2022). Poor mental health can prevent students from having good study habits, increase procrastination and can lower achievement in school. College students with major depression have poorer study habits, greater procrastination, and lower academic performance (Jeffries and Salzer 2022).

Changes in climate such as higher temperatures and precipitation can also affect the distribution and spread of certain infectious diseases that adversely influence children's schooling attendance and educational achievement. Vector-borne diseases such as malaria, dengue and Lyme disease are highly sensitive to climate and are expected to increase in many global regions in the context of climate change (Caminade et al. 2019). Additionally, the suitable conditions for some of these vectors are shifting to new locations, producing a burden in regions and populations that were previously unexposed and have decreased immunity to these diseases (Mordecai et al. 2020). Children in Uganda have lower reading scores after cerebral malaria, a type of neurological complication from the malaria parasite most prevalent in Africa (Nakitende et al. 2023). A study in Denmark found that students that were hospitalized for an infection in childhood had 0.82 (95 percent confidence interval: 0.79–0.85) lower odds of completing ninth grade (Köhler-Forsberg et al. 2018).

Extreme weather events can affect sleep, which is an important driver of academic performance and achievement (Eide and Showalter 2012). Higher temperature has been associated with increases in sleep apnea and other sleep problems (Rifkin et al. 2018). A study in the United States found that when monthly nighttime temperature changes by 1°C, a three-night increase in insufficient sleep is observed per 100 persons (Obradovich et al. 2017). Sleep disturbance is also an effect of wildfires—a systematic review of the impact of wildfires on sleep found that approximately 63–72.5 percent of wildfire survivors have insomnia and 33.3–46.5 percent have nightmares up to 10 months following the disaster (Isaac et al. 2021). A review on climate and sleep by Rikfin et al. (2018) found a higher rate of disrupted sleep for those affected by the 2011 summer floods in Brisbane, Australia and flood victims in China which was related to fear and depression (Rifkin et al. 2018). Another study on sleep problems and posttraumatic stress symptoms for elementary school-aged children exposed to Hurricane Ike in Texas found that sleep problems were prevalent and that they persisted in the second year following the disaster (Lai et al. 2020). The optimal number of hours of sleep is higher for younger populations and lower sleep is associated with lower scores in math and reading tests (Eide and Showalter 2012). For example, students at age 12 and 16 perform 0.035 and 0.045 standard deviations lower on tests, respectively, when sleeping 1 hour less than their optimal hours (Eide and Showalter 2012).

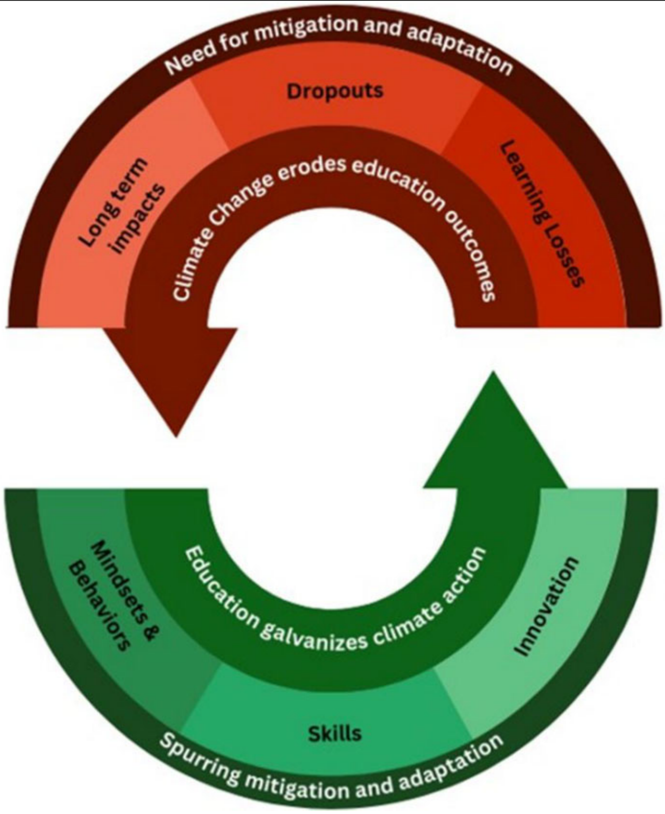
Learning and education is also impacted indirectly through health shocks that affect children starting in-utero. A study on climate change and education in tropical regions found that a child in Southeast Asia exposed to high temperatures (2 SDs above average) in the prenatal period or early in life has 1.5 less years of schooling than a child with average temperature exposure (Randell and Gray 2019). Rainfall shocks during a child's first year of life in a pastoralist region of Kenya lowered academic achievement and cognitive skills, reducing reading skills by 13 percent for example, although shocks that occurred later in life were found to be less impactful (Nübler et al. 2021). A study evaluating the effect of El Niño droughts found that children who were not exposed to extreme weather conditions in utero and early childhood had a 5 percent higher likelihood of staying in school and an increase of 0.05 standard deviation in scores for high school exit exams (Duque et al. 2018). Another study found that disability rates increased by 3.5–5.2 percent for those exposed to droughts in infancy for South Africans who were sent to live in rural and isolated pockets of land during apartheid (Dinkelman 2017). Exposure to extreme heat in utero has also been associated with increased risk of preterm birth and low birth weight (Bekkar et al. 2020). Preterm infants have been shown to have 1.57 (1.33–1.86) higher odds of having special education needs in school (Odd et al. 2016) and are at higher risk of poor educational achievement (Quigley et al. 2012). A review of the executive functions of children born preterm or low birthweight found that they had lower working memory (by 0.5 of a standardized mean) and inhibition (by 0.4 of a standardized mean) (van Houdt et al. 2019). This will produce intergenerational effects from extreme weather events by impacting the future schooling and education of children even before birth.

In the long term, high temperatures and extreme weather events can drive conflict, migration, and displacement that can affect the ability of students to have continuous learning and school attendance. It is projected that by 2050, tens of millions of people will be forced to migrate within their countries due to climate change (Rigaud et al. 2018). A meta-analysis on climate and conflict found that a one standard deviation change in climate (temperature and rainfall) can increase the risk of intergroup conflict by 14 percent and of interpersonal violence by 4 percent (Hsiang et al. 2013). Conflict, violence, and war have consequences for children's educational attainment and achievement. A study from Burundi not only found that children exposed to war were stunted but that they completed 0.7 fewer years of school, on average, and later in life earned 21 percent less (Akresh 2016). Similarly, a study from Peru found that children exposed to Peru's 1980–93 civil war early in life had 0.3 less years of schooling in adulthood (Galdo 2013). A study of populations affected by the Bosnian war also found that displaced parents spend less on their children's education (Eder 2014). Evidence from the study on the Peruvian civil war not only showed that children exposed to the war in the first three years of their lives had lower education but that this translated to 5 percent lower monthly earnings in adulthood and a lower probability of working in the formal economy (Galdo 2013). High temperatures can also have long-term impacts on national wealth (Zivin and Shrader 2016). Ultimately, the pathways through which extreme weather impact education outcomes unequivocally result in lower learning and educational attainment, both of which are key to reap the economic benefits of education. As we witnessed with the COVID-19 pandemic, resulting learning losses and lower levels of educational attainment reduce incomes, productivity, and amplify existing inequalities (Azevedo et al. 2022).

Protecting and Leveraging the Education Sector

To minimize detrimental impacts of climate change on education outcomes, it will be important to promote adaptation and resilience in the education sector. This is particularly urgent because these detrimental impacts will continue to become more severe. However, the scale of the impact will depend on the ultimate depth of the climate crisis. A country like Ethiopia will experience a median of 138 hot days (above 35°C) under a pessimistic (SSP5-8.5) scenario, compared to 81 days under a middle of the road (SSP2-4.5) scenario; implying very different impacts on education outcomes. While adaptation is undeniably needed to meet the challenges of already-happening climate change, mitigation can still play a critical role in limiting the magnitude of the impacts. The education sector is uniquely positioned to galvanized climate action (fig. 2). Education can spur mitigation through changing mindsets and behavior, producing skills required for

Figure 2. The Bi-Directional Relationship of Climate Change and Education



Source: Author's illustration.

a green transition and prompting innovative strategies and action for climate mitigation and adaptation.

The Need to Urgently Adapt Education Systems

Even if the most drastic climate mitigation strategies were implemented, we will continue to observe increasing frequency and intensity of extreme weather events which have detrimental impacts on education outcomes. Actions can be implemented to increase the capacity of education systems to adapt and cope with these increasingly prevalent climate stressors, such as encouraging investments in adaptation (Behrer 2023). Prior to the construction of new schools, an evaluation of predicted future climate impacts including sea level rise, ambient temperatures and extreme weather events can be used to select appropriate locations (Theirworld 2018). In existing schools, integrating climate-resilient strategies will be increasingly critical. In response to extreme heat, schools and classrooms can ensure ventilation and/or air conditioning to keep temperatures at a comfortable level for students to ensure the best learning outcomes. For cyclones, schools in at-risk regions can implement measures to prevent infrastructure damage and limit school closures during a storm and their associated impacts. For droughts, school nutrition programs can be effective to prevent impacts on food security and associated learning. For wildfire smoke, air filtration systems can be installed in schools and classrooms to reduce student exposure to air pollution. Furthermore, actions can be implemented to predict, prepare and assess extreme weather events and incorporate disaster response in education sector plans. More than 40 percent of World Bank investments in the education sector are focused on education facilities, creating an opportunity to increase their resilience to climate stressors (World Bank 2024).

Interventions can be implemented at the school and classroom level to reduce the burden of extreme heat for students in the classroom. Strategies to include thermal comfort in schools include increasing natural ventilation and/or accessibility to air conditioning in the classroom (Haverinen-Shaughnessy and Shaughnessy 2015; Singh et al. 2019). A meta-analysis on the relationship between classroom temperature and children's performance estimated that reducing classroom temperature from 30°C to 20°C could increase performance in learning-related tasks by 20 percent (Wargocki et al. 2019). Porras-Salazar et al. (2018) conducted a cross-over trial with elementary school students in Costa Rica in which air conditioning units were used to reduce classroom temperatures from about 30 to 25°C. The 11-year-old students showed an improved performance in lower classroom temperatures; speed in cognitive tests increased up to 7.5 percent, and accuracy increased by 0.6 percent for each degree of reduction in classroom temperature (Porras-Salazar et al. 2018). Interestingly, this effect was stronger for lower performing students. The authors suggest that decreasing indoor temperatures can be a strategy to combat inequalities since the children who performed worse on exams were the most affected by high classroom temperatures (Porras-Salazar et al. 2018).

Resilience-building initiatives that target root causes focusing on disadvantaged schools and populations can also be effective strategies to limit detrimental impacts of heat (Sheffield et al. 2017). Ensuring natural ventilation and climate-responsive designs of schools can be alternative strategies to air conditioning which may not be feasible in all contexts. For existing schools, less costly options range from painting rooftops with solar-reflective white paint, increasing tree coverage in and around the school, and even adapting school schedules to avoid hours with extreme heat. For new school constructions, the use of certain materials such as clay to offer thermal protection or the design of roofs to ensure ventilation can be effective in limiting heat in classrooms (see Gando Primary School as a good example). School construction integrating natural daylight and cross-ventilation as well as trees and/or shade structures can reduce the energy needed (Chalupka and Anderko 2019). For example, Kenya implemented a

Green Economy Strategy and Implementation Plan that promotes bioclimatic design for school buildings and will increase thermal comfort for students during high temperatures (Odera 2020).

Adapting education systems to be more resilient to typhoons, droughts and wildfire smoke may involve action at multiple levels, including increasing the resilience of the school as well as establishing learning recovery or nutrition programs. Increasing the resilience of the school to prevent closures during disaster will likely be the most effective strategy, and can include actions such as construction of walls to prevent damage from floods or changes in land-use management (Theirworld 2018). Schools and education systems can also implement actions to limit their effects on student achievement and attendance.

There are some good examples of addressing learning losses after school closures. An after-school program in Tamil Nadu, India helped recover half of the learning losses from COVID-related school closures via 60–90 minutes of daily remedial learning for six months (Singh et al. 2022). School nutrition programs can be effective in reducing impacts of droughts on nutritional outcomes (Taras 2005). Installing air filtration systems has been shown to be an effective adaptation strategy to reduce exposure to wildfire smoke (May et al. 2021). One study evaluated potential benefits of installing air filtration systems for student achievement and found that it can increase student achievement and performance (Gilraine 2023).

Forecasting and predicting extreme weather events can be important not only to prevent adverse health impacts of these events, but also their impacts on education outcomes. If schools receive sufficient warning about a potential climate shock, they may be able to prepare and protect the students that are most vulnerable. Novel forecast-based financing systems have also been proposed to identify and provide funding support to regions for post-disaster response (Coughlan de Perez et al. 2015). By identifying at-risk regions before the climate shock occurs, appropriate actions can be activated to increase resilience. Nearly 60 percent of countries in a 2017 survey of 68 high-risk countries for disasters include either disaster risk reduction or disaster response components in their education sector plan, but these are not always comprehensive (GPE 2023). For example, the Philippines implemented early warning systems for typhoons, floods, and earthquakes through a mobile app that is used by the education system to improve the disaster knowledge of students and staff and help them take action (Aranda 2022).

Policymakers and educational planners should work together to ensure climate-ready schools and systems in the context of climate change and the link between disaster planning frameworks and the education sector should be strengthened (GPE 2023). The involvement of students in disaster risk reduction and management at local, regional, and global levels is an underutilized strategy that can be critical for resilience development (Pal et al. 2023).

It has been estimated that the increased mortality risk from temperature change corresponds to approximately 3.2 percent of global GDP by 2100 under a high emissions scenario, which will be worse in poorer regions of the world (Carleton et al. 2022). While adaptation measures will be essential to limit destructive impacts, they do have significant costs that will continue to increase in the context of climate change. For example, per capita median annual adaptation costs in developing countries are projected anywhere from US$17 to US$26 in 2050, depending on which climate path we take (Chapagain et al. 2020). Also, adaptation strategies will be increasingly costly. As extreme weather events become increasingly severe, the effectiveness of these measures decreases due to the higher frequency and severity of these events. Therefore, relying solely on adaptation will not be effective in order to avoid the detrimental impacts of climate change, and there is copious evidence to show the importance of acting on climate now to prevent catastrophic impacts.

The Need to Leverage the Education Sector for Climate Action

Empowering children and youth with education paves the way for effective climate change adaptation and mitigation. There is a strong and positive relationship between education and the capacity to adapt to climate change.

More educated individuals are better able to prepare for, cope with, and recover from extreme weather events. Evidence from Senegal, Mali, Thailand, Cuba, Haiti, the Dominican Republic, El Salvador, and Brazil provides robust evidence for the positive impact of education on vulnerability reduction (Wamsler et al. 2012; Muttarak and Pothisiri 2013; Pichler and Striessnig 2013; Van der Land and Hummel 2013). In these studies, people with higher levels of education exhibit greater disaster preparedness and response, experience reduced adverse effects, and recover more quickly from disasters.

Evidence suggests that there are direct and indirect pathways that support this positive relationship. Education attainment directly influences risk perception, skills, and knowledge, all of which empower individuals to be better prepared against extreme weather events and thus reduce impacts. Education, from early years to adulthood, promotes cognitive development and vital skills that are key for adaptive capacity. UNICEF estimates that improving educational outcomes could reduce the climate risks borne by 275 million children globally (UNICEF 2021b). Indirectly, higher levels of educational attainment reduce poverty, improve health, and slow down population growth, all of which are linked with higher community-level adaptive capacity (Muttarak and Lutz 2014).

Beyond adaptation, evidence also suggests a strong and positive relationship between educational attainment and mitigation practices. An additional year of education has been found to increase pro-climate beliefs by 6.3 percent, change behavior by 8.5 percent, and produce a 35 percent increase in green voting across 16 European countries (Angrist et al. 2023). In China, educational attainment is associated with a 2 percent increase in pro-environmental attitudes and behaviors (Wang et al. 2022). Similarly, in Thailand, a study found that additional years of schooling are associated with knowledge-based environmentally friendly actions such as increasing regular use of cloth bags by 5 percent and energy-efficient appliances by 7.7 percent (Chankrajang and Muttarak 2017). Globally, the level of education attained emerges as the most influential factor in predicting climate change awareness, with an understanding of human-induced climate change being the primary predictor of perceptions regarding climate change risks (Lee et al. 2015). Education also exhibits a robust correlation with environmental concern and support for policies that benefit the environment (Chankrajang and Muttarak 2017).

Education can help galvanize mindset and behavior shifts through exposure to timely information, ideas, and nudges to action. As much as 20–37 percent of the emissions reduction needed to achieve net zero depends on individual and household behavior change (Williamson et al. 2018). Students who completed a year-long university course focused on topics related to climate change managed to lower their personal carbon emissions by an annual total of 2.86 tons of CO2 (Cordero et al. 2020). Addressing climate change also requires demand for policy changes that prioritize climate action and willingness to bear the costs of those changes. Studies show that there is a strong positive correlation between education, concern for the environment, and behaviors that support political decisions that have a positive impact on the environment (Franzen and Vogl 2013; Meyer 2015; Chankrajang and Muttarak 2017).

The education sector is also uniquely positioned to develop the skills needed to advance the green transition. The shift of the global economy towards more sustainable and climate-resilient growth that prioritizes low-carbon development precipitates the need for a skilled workforce that can carry out the array of tasks associated with greener jobs. Studies show that there is a strong positive correlation between education and the kinds of skills (e.g., problem-solving and critical thinking) that support policies that have a positive impact on climate change (Franzen and Vogl 2013; Meyer 2015; Chankrajang and Muttarak 2017). Compared to non-green jobs, green occupations exhibit a stronger intensity of high-level cognitive skills (Consoli et al. 2016). Education can play a critical role in building skills to power the transition to green and resilient economies and jobs.

Finally, as the quest for innovative solutions to bolster climate adaptation and mitigation gains momentum, educational institutions have the potential to thrive as dynamic centers of innovation. In terms of mitigation, innovation is key to eventually achieving net-zero emissions. Almost 50 percent of the emission reductions to achieve net-zero by 2050 depend on technologies that are at the prototype or development stage (IEA 2020). Even in the case of diffusing existing technologies, contextualizing and scaling up these technologies requires significant research to find effective ways of enhancing deployment. Investing in innovative technologies is associated with lower

CO_2 across emerging countries (Afrifa et al. 2020). Universities can be hubs of innovation and knowledge creation to innovate and advocate for solutions to climate change (Leal Filho et al. 2023).[5]

Conclusion

Evidence unequivocally shows that extreme weather events—high temperatures, tropical cyclones, droughts, floods, and wildfires—harm learning, educational attainment, and human capital accumulation. The harm comes in the form of direct and indirect impacts, especially among the most vulnerable children in the most vulnerable settings. As climate change increases the frequency and intensity of extreme weather events, these impacts and the inequities they amplify are likely to grow. In the absence of effective adaptation measures, with more frequent school closures due to extreme weather events and less comfortable classrooms due to high temperatures, learning outcomes and enrollment rates will be significantly and negatively impacted. Thus, eroding a lot of the progress made on education outcomes in recent decades.

Both mitigation and adaptation are urgently needed. Climate resilience in schools can be increased by infrastructure and programmatic changes. Improvements in infrastructure such as access to air conditioning, low-cost strategies to control classroom temperatures, air filtration systems and walls to prevent flooding can protect students from the adverse impacts of heat, wildfire smoke, and floods. Providing nutrition and remedial learning programs can also be effective strategies to increase the resilience of affected students. The costs of adaptation will become increasingly severe under climate change, and our ability to implement climate change strategies will determine the extent of the need for adaptation. Climate change mitigation often outweighs the costs and can have benefits on other sectors.

Education can play a catalytic role in climate change mitigation and adaptation by reshaping mindsets, behaviors, voting preferences, skills and innovation. In general terms, educational attainment is strongly correlated with higher adaptive capacity for individuals and their communities. It is also found to be intrinsically associated with preferences and behaviors that support climate mitigation. Emission reductions will need to come from individual behavior change alongside larger national plans to shift economic activity away from carbon-intensive growth and towards greener and more sustainable growth models. These large-scale shifts, largely captured in Nationally Determined Contributions (NDCs), precipitate the need for a population that will support these policies and a skilled workforce capable of implementing them. In this context, the education sector is uniquely positioned to empower children, youth, and their communities with the mindsets, behaviors, skills, and innovative ideas that this climate crisis requires. In the words of Mere Vadai, a youth climate activist in Fiji, "The classroom is where we begin transforming climate knowledge into action."

Data availability

Regarding data access, no new data were generated or analyzed during this study.

Conflict of Interest

The authors declare no conflicts of interest.

Notes

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1. First three pages of Google Scholar search of search terms climate AND impact AND economic, including only articles published 2010 and onwards that are review articles on the broad impacts on economy/society and excluding articles on a specific sector, with a focus on methods, or that have a specific regional focus.

2. A Web of Science search on the topic "climate and impact" with the search terms "health" resulted in 24,980, "economic" produced 31,243, and "education" produced 5,732. From these results, we can conclude that there is four-times more research on the economic impacts of climate and five-times more research on the health impacts of climate than there is research considering the educational impacts of climate. Out of the 5,732 results from Web of Science on climate impacts on education, 1,903 (33 percent) are based in the United States and 4,467 (78 percent) are from high-income economies (based on World Bank classifications). This is based on Web of Science classifications and may not describe where the research for the manuscript is based.

3. To estimate days of learning lost, it was assumed that students are expected to learn about 0.3 standard deviations in a given academic year (Schady et al. 2023), and such a year is comprised of about 180 school days. Days of learning lost were estimated with the following equation: Days of learning lost = $\frac{\text{SD}_{\text{change}}}{0.3\ \text{LAYS}} * 9\ \text{months} * 20\ \text{days}$

4. When estimating overall effects of classroom temperature on test scores, studies ranged from elementary- to college/university-level students. Estimates assumed that the effect of temperature on achievement is linear.

5. A comprehensive analysis of how education can support climate change mitigation and adaptation can be found in Sabarwal et al. (forthcoming).

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